Strategic Property Buyouts to Enhance Flood Resilience

Creating a model for flood risk reduction, community protection and environmental protection

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In collaboration with and support from The Nature Conservancy

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Executive Summary

The impact of recent flood events such as hurricane Harvey and the repetitive flood losses experienced by properties in the Houston metropolitan area have led to multiple proposals for reducing flood damages in the area. One such proposal includes buying out chronically-damaged properties to return them to more natural open space areas. While multiple analyses show significant flood reduction benefits from the protection of open spaces there is a paucity of studies that also consider the complementary ecological benefits or co-benefits of buyout programs. For example, the criteria for selecting property acquisition due to flooding often ignore proximity to important ecological features such as wetlands and protected areas, as well as ongoing open space restoration plans and projects.

Protecting open space and critical natural resources are becoming important tools with which to mitigate the adverse effects of flooding. However, land acquisition and buyout programs are almost always initiated in a reactionary, ad hoc manner after a flooding event has occurred. This approach often results in an uncoordinated, checker-board pattern of open spaces that does little to protect environmental assets or remove groups of structures from areas vulnerable to flooding over the long term.

This study addresses the problem by developing a proactive framework for identifying candidate parcels for acquisition in advance of storm events. Specifically, we identify the proximity of damaged properties to important ecological features as an additional criterion for selecting buyout properties for land acquisition. This approach enables the selection of properties with the potential of being restored to open spaces as well as serve important natural flood attenuation purposes. Importantly, we show that including these criteria do not significantly reduce the cost effectiveness of buy outs as a strategy for flood mitigation.

The study team performed a coupled analysis of actual flood claims and flood loss estimation to over 74,000 properties affected by Hurricane Harvey and created a proximity matrix of different ecological features such floodplains, wetlands, parks, conservation zone and protected areas. Additionally, to prevent a checker-board pattern of candidate buyout properties (Robinson et al., 2018), we restricted selection eligibility to properties in close proximity to existing buyouts. After developing a comprehensive database of distance matrices and losses, we analyzed four example scenarios with varying ecological criteria while prioritizing properties in areas that are socially vulnerable and have disproportionate access to housing and transportation in Harris County.

The results of our analysis show a flood damage to appraised market value of about 1.45 to upwards of 2.67 across multiple scenarios, implying that candidate parcels have significant benefits if included in the buyout program. Our results also show that extending FEMA requirements to consider ecological selection criteria generates upwards of 1,100 potential buyout properties in Harris County, TX, with market values ranging from $1.37 - $135.06 million. These findings show how acquiring parcels for flood risk reduction can be combined with protecting ecological values in a way that helps communities to become more resilient over the long term. This study also provides a methodological framework for effectively selecting parcels for multiple values in other jurisdictions across the United States (U.S.).

Contents

Introduction

Protecting open space and restoring critical natural habitats are becoming important tools with which to mitigate the adverse effects of flooding. However, land acquisition and buyout programs to acquire open spaces are almost always initiated in a reactionary, ad hoc manner after a flooding event has already occurred. Although previous research shows that protecting and restoring open spaces can reduce flood risk (e.g. White, 2011; Tate et al, 2016), there is a paucity of studies that also consider the additional social and ecological benefits of buyout programs. This often results in an uncoordinated, checker-board pattern of open spaces that does little to protect environmental assets or remove groups of structures from areas vulnerable to flooding over the long term. Previous studies have also raised concerns about checker-board patterns of buyouts that limit opportunities for creating connected patches of open space. Also noted is the increasing costs of landscaping and maintaining small isolated parcels of open space in residential neighborhoods (Maly & Ishikawa, 2013; Freudenberg, Calvin, Tolkoff , & Brawley, 2016; Zavar & Hagelman III, 2016; Robinson et al., 2018). Some buyout programs, such as New York Rising and New Jersey Blue Acres, have begun to incentivize large housing blocks to volunteer their property for acquisition after a flood event, however there is a lack of information available in Texas and across the nation on how to systematically identify and purchase flood-prone properties to reduce future flood losses and restore large patches of open space (Siders, 2013; Freudenberg, et al, 2016).

Project Goals and Objectives

The Nature Conservancy and Texas A&M University partnered on a study to examine whether a more proactive approach to buyouts could be designed that enhances environmental value while remaining a cost-effective option for reducing future flood losses. We selected Harris County, Texas as the study area as this jurisdiction already has the most flood buy-outs in the nation and is poised to significantly expand its program post-Hurricane Harvey in 2017.

Our study developed and tested a proactive framework for identifying candidate parcels for acquisition in advance of storm events and for post-storm buyouts. This framework allowed us to analyze different scenarios that include a range of buyout criteria, ranging from a current practices approach to one that prioritized parcels in close proximity to other buyouts, existing natural features and open spaces. Specifically, we sought to:

- Examine the pattern and spatial characteristics of previous parcel buy-outs and open spaces in Harris County, Texas.
- Develop a multi-criteria, spatial method for selecting candidate buyout parcels that prioritizes additional parameters outside of the current buyout selection criteria. Multiple factors were explored, including: the pattern of previous buyouts, naturally-occurring wetlands, critical natural habitats, adjacent ecological assets, proximity to other open spaces, previous flood damage, value of property, etc.

- Calculate a damage-to-market value ratio for selected candidate buyouts considered under each scenario to assess whether they are cost-effective approaches.
- Compare the spatial distribution and cost-effectiveness of buy outs for multiple scenarios.

Background on Property Buyouts for Flood Mitigation

The U.S. government first passed the Mitigation Act after the catastrophic 1993 Midwest flood, which caused 50 deaths and over $15 billion in losses. This act made provisions for property acquisition and relocation assistance, making it possible for properties to be converted to open space and allow homeowners to qualify for a buyout from the federal government at a pre-flood price (Fraser et al., 2003). The most common and largest of these programs is the Federal Emergency Management Agency's (FEMA) hazard Mitigation Grant Program (HMGP), which provides 75% assistance from FEMA and the remaining 25% from other local agencies (Conrad et al., 1998; White 2011). The acquired lands are subsequently reserved as open spaces and sometimes restored for other ecological purposes (Fraser et al., 2003; Zavar and Hagelman III, 2016; Tate et al., 2016).

Characterizing Buyouts in Harris County

Under the HMGP, FEMA has dedicated approximately $555 million in Texas, which has led to the acquisition of over 4,380 properties. Since 1989, about $205 million of this total was used to acquire 1,618 properties in and around the Houston area. FEMA estimated that these Houston-areas acquisitions avoided loss of over $330 million with a return on investment ratio of 1.61 (FEMA, 2017). Today, Harris County has more flood buyouts than any other county in the United States. The Harris County Flood Control District (HCFCD) has spent $342 million since 1997 to acquire about 3,100 properties funded primarily by the HGMP program. These investments have restored over 1,000 acres back to the floodplain (see Figure 1). Figure 2 shows the distribution of buyouts in the county. The majority of sites are concentrated in the floodway adjacent to bayous and other water bodies where much of the flood risk occurs.

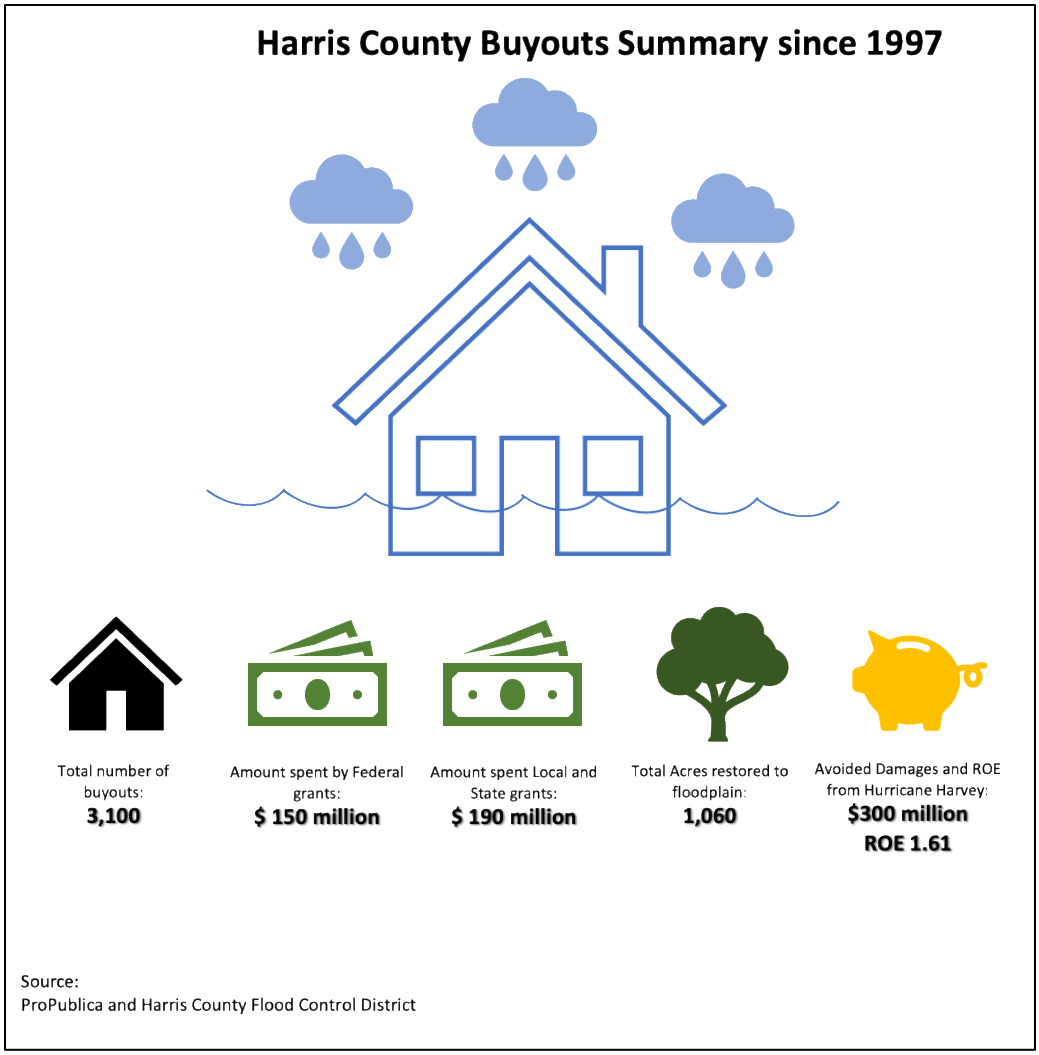

Figure 1. Buyouts statistics in Harris County, TX since 1997.

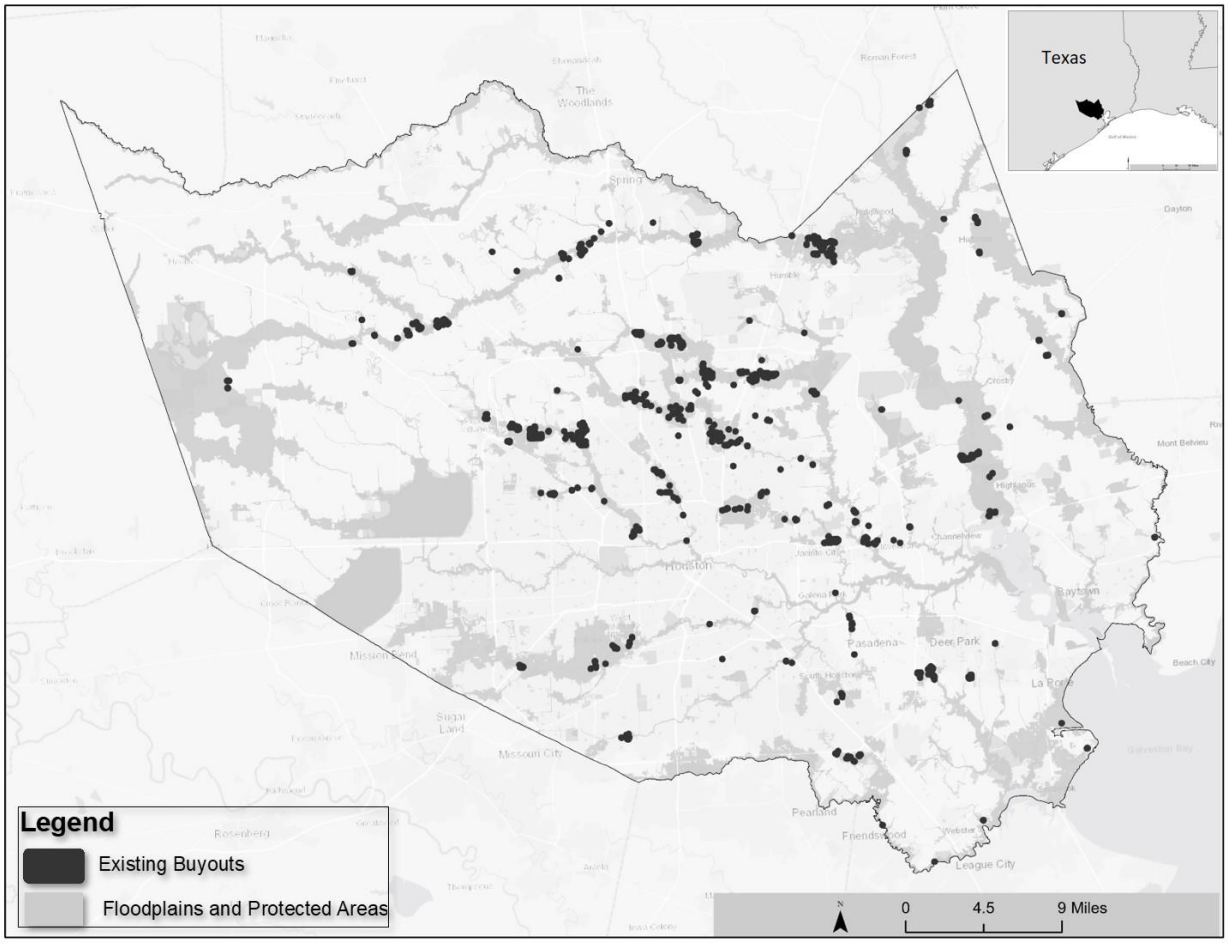

Figure 2. Existing Buyout locations in Harris County.

Benefits of Property Buyouts and Land Acquisition

Flood attenuation has long been considered a major benefit of land acquisition and open space protection (Beatley, 1994). Protecting land for flood mitigation can also support ecological functions, such as wetland protection and floodplain restoration (Conrad et al., 1998; Harter, 2007). After acquisition, parcels of land can be restored and managed for multiple benefits including recreation, conservation, education, habitat restoration, reducing soil erosion, and improving water quality (Conrad et al., 1998; Harter, 2007; Zavar & Hagelman, 2016; Hanson & Lemanski, 1995).

In quantifying the ecological benefits of property acquisition, Zavar and Hagelman (2016) reviewed buyout sites across the U.S. and found that communities participating in HMGP buyout-funded programs restored about 6.9 percent of acquired land to wetlands. An additional 13.5 percent were eventually restored to wetlands under capital improvement projects. Buyouts that have been converted to natural areas can provide economic benefits, such as increased property values and opportunities for recreation (FEMA, 1998).

Strategic buyouts can also provide social benefits to the community. Social vulnerability to natural hazards has been widely studied in the hazards literature and frequently asserts that socially vulnerable groups have a lower capacity to 'anticipate, cope with, resist, and recover from the impact of a natural

hazard" (Wisner et al., 2004, p. 11). Buyouts can be used to strategically reduce this vulnerability by acquiring parcels in the most vulnerable communities. For example, Tate et. al. (2016) found a positive association between standardized benefit-cost ratios and social vulnerability, suggesting that structures that had positive benefit-cost ratios were also likely to be found in socially vulnerable areas.

Several methodologies exist for mapping and identifying socially vulnerable communities. Social vulnerability indices, such as the Social Vulnerability Index (SOVI®) (Cutter et al., 2003), and the Center for Disease Control's Social Vulnerability Index (SVI) (CDC, 2015) include indicators, such as socioeconomic status, race, age, ethnicity, health coverage, housing and transportation, and can be used to map clusters of socially vulnerable groups.

Methodological Approach

To evaluate the cost-effectiveness of a framework for buy-out selection that considers ecological values, we first analyzed the spatial characteristics of previous flood buy-outs in Harris County, TX. Next, we mapped and measured the proximity of open spaces and different natural features within Harris County. This spatial database of parcels, previous buyouts, and natural features allowed us to compare the cost-effectiveness of multiple buyout selection scenarios. Our basis for evaluating the cost effectiveness for land acquisition depended on comparing observed and estimated damages from Hurricane Harvey to the appraised market value of the damaged property. Four different scenarios were evaluated, ranging from the current practice scenario to one that promotes clustering of buyouts in close proximity to natural features such as wetlands and protected areas.

Flood Damage Modeling

Cost effectiveness of land acquisition was calculated by comparing damages from Hurricane Harvey to the appraised market value of the damaged property. To determine the amount of damages from the storm, we first calculated federally-insured flood claims payments under the National Flood Insurance Program (NFIP). This dataset includes an inventory of all flood claims and payments for each parcel for damage to the structure and its contents (see: Highfield, Brody & Blessing 2014; Highfield & Brody 2012; Atoba, 2018 for more information).

Second, because the NFIP dataset is limited to only insured flood damages and does not reflect flood losses to uninsured properties, both within and outside the floodplain, we supplemented the Harvey flood claims by performing flood loss estimation using Hazus-MH, a GIS-based software created by FEMA. This program estimates losses to general building stock, indirect losses, and other social impacts from flooding and earthquake hazards (FEMA, 2006; Scawthorn et al., 2006). Hazus-MH is a useful decision-making program as it estimates the possible economic benefits of both structural and non-structural flood mitigation strategies for a large region like our study area.

Because there is a significant degree of uncertainty associated with default Hazus-MH datasets and modelling, we developed the model with improved datasets and higher-resolution inundation data and depth-damage curves, all of which improve the reliability of Hazus-MH flood damage estimates and reduce measurement bias (Ding et al. 2008; Tate et al. 2014). We also revised the model with more current and granular elevation data (LiDAR) and structural characteristics.

More specifically, we used a 3-meter resolution Harvey flood-depth grid to determine the extent of inundation for each residential property in Harris County. For flood loss estimation, important datasets

like building location, square footage, foundation type and first floor elevation data were collected from the Harris County Appraisal District for each property in the study area. First-floor elevations were estimated based on their respective foundation types. Where foundation types were missing, we assumed slab-on-grade foundation and assigned the associated value of the first-floor elevation for the property. Finally, we calculated the total losses (structure + contents) to each property using damaged curves provided by the US Army Corps of Engineers (USACE) appropriate for the area based on the building occupancy type, number of stories and foundation type relative to the depth of flood inundation for each building (see Figure 3).

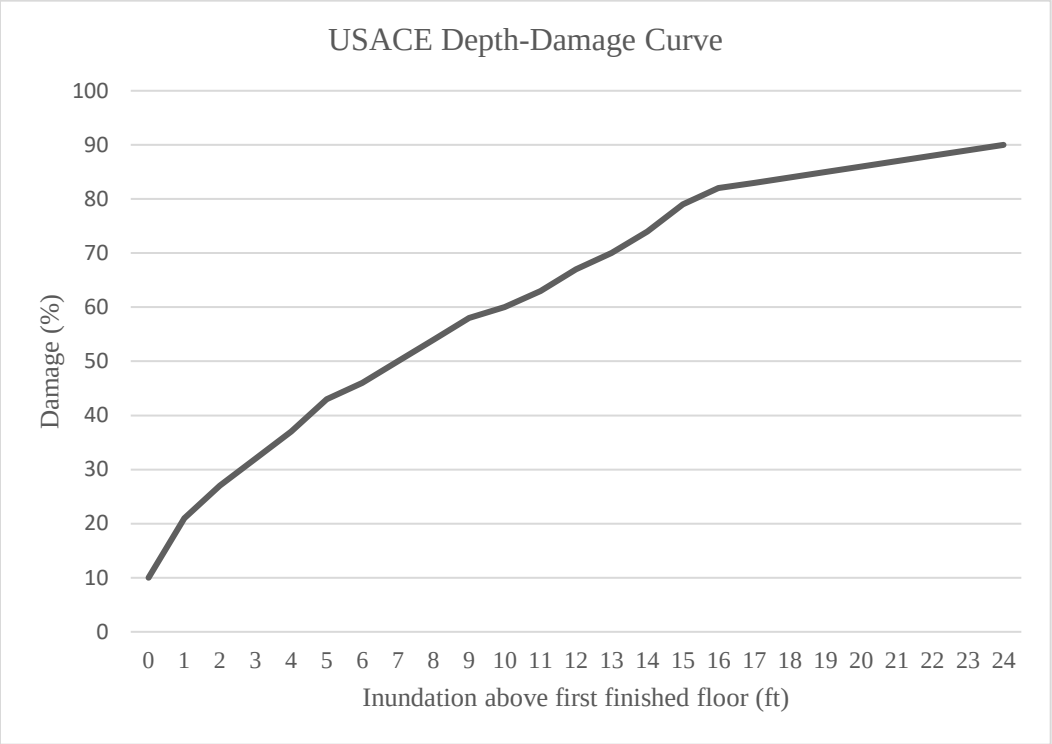

Figure 3. Sample USACE Depth-Damage Curve for a 1-story Single Family Home in a A-zone with slab foundation. This is one of the damage curves used in the flood loss estimation.

A combination of Harvey flood claims from FEMA and the loss estimation in Hazus-MH resulted in a complete dataset of properties that experienced losses from Hurricane Harvey. We prioritized the flood claims dataset over the loss estimation as these provide a more realistic dollar equivalent of losses from the flood event. A step-by-step flow chart of our modeling process is displayed in Figure 4.

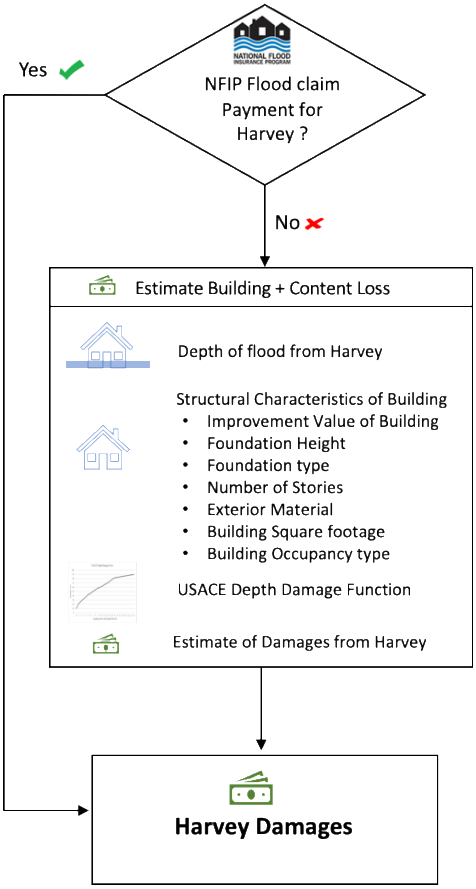

Figure 4. Modeling process to measure flood losses from Harvey in Harris County, TX.

Table 1 shows the summary statistics of the base dataset from which the candidate buyouts were selected. As mentioned above, the study sample consists of all properties that have either flood claims from NFIP or have property damages from Hazus-MH flood loss estimation. Our results show that a total of 72,271 properties were damaged from Hurricane Harvey (in Harris County) totaling approximately $6.3 billion with an average household damage of about $87,000. Total market value of the damaged properties is about $17 billion; the average market value of the damaged properties is about $230,000. Out of all properties affected by Hurricane Harvey, there are approximately 3,500 properties that have experienced repetitive flood losses with a total claim amount of about $634 million between 1978 and 2017.

For each buyout scenario, we calculated a Damage-Market Value Ratio (DMVR) to better understand the financial consequences of acquiring properties for flood risk reduction purposes. This variable was measured as the total flood loss (Harvey and previous flood events) for all parcels being considered divided by the assessed market value of the property. This variable signifies the amount of financial loss that would have been avoided if the properties were acquired and taken off the tax roll, even when considering the loss of economic value. We assume that *a ratio higher than 1 indicates that the scenario would have a net financial benefit to the community.* We also calculate proximity of the damaged Harvey parcels to several ecological features identified above. For example, the average distance of damaged parcels to existing flood buyouts is about 10,000 feet, with the smallest distance about 32 feet. Mean distance to wetlands and floodplains are about 1,000 and 771 feet respectively; distance to parks averages about 2,244 feet; distance to protected areas within the study area 3,543 feet.

Table 1. Summary Statistics of Claims and Buyout Parcels (n = 72,271).

Measure	Min	Max	Sum	Mean	SD
Damage ($ million)	0.0000006	5.53	6,289.48	0.087	0.094
Market Value ($ million)	0.0037	11.87	16,680.25	0.23	0.232
Repetitive loss total ($ million)	0	3.08	634.69	0.0087	0.093
DMVR (ratio)	0.000019	30.31	34170.51	0.4728	0.621
Buyout Distance (ft)	32.15	67,136.59	739,887,535	10,237.68	9,383.21
Floodplain distance	0	8,451.01	73,090,350.64	1,011.34	1,309.18
Wetland distance	0	8,061.36	55,739,058.68	771.25	687.17
Park distance	0	28,656.30	179,020,372.38	2,477.07	2,244.51
Protected Areas	0	28,928.33	256,097,768.65	3,543.58	3,376.04

Buyout Selection Scenarios

We analyzed four buyout selection scenarios by calculating the distance from each of the 72,271 parcel centroids to the edge of the following existing features: floodplains, wetlands, parks, conservation easements, protected areas, and existing buyouts (see Table 2). To ensure that property acquisitions are financially beneficial, we excluded candidate properties with market values of $5,000 or more than the damages recorded from Hurricane Harvey.

The following four buyout scenarios were sequentially analyzed using the database of parcel attributes:

1. ***Current Practice:*** We began our analysis by analyzing a baseline scenario of the existing requirements for buyouts used by the Harris County Flood Control District (HCFCD). Currently, HCFCD considers properties for buyouts only if they lie deep within the 100-year floodplain, are affected mainly by riverine flooding, have potential for being used for floodplain preservation, and are supported by community funding. These criteria are in addition to the federal eligibility requirements that dictate properties be cost beneficial and be covered by flood insurance policy. We also created an extension of this scenario

by restricting existing FEMA requirements to within 500 feet of all ecological features of parcels damaged by Hurricane Harvey.

2. ***Proximity to Wetlands, Floodplains and Buyouts:*** Our scenario category examined properties that are located near existing FEMA-defined 100-year floodplain boundaries and wetlands designated in the National Wetland Inventory database. Unlike Harris County requirements, this approach allows for the consideration of additional properties affected by Harvey located outside of the 100-year floodplain. We tested two distance thresholds to better understand what types of thresholds would be appropriate when considering proximity as a selection criteria: 500 and 1000 feet.
3. ***Parks, Protected Areas and Buyouts:*** In the third scenario category, we prioritized properties affected by Harvey in close proximity to existing parks, conservation easements, protected areas, and existing buyout parcels. We again tested two different distance thresholds of 500 and 100 feet. Properties that were farther than 500 or 1,000 feet from these features were excluded from the selection process.
4. ***All Natural Features and Buyouts:*** The set of scenarios prioritized properties affected by Harvey that are in close proximity to all ecological features measured in this project (i.e., floodplains, wetlands, parks, conservation easements, and protected areas) and existing buyouts. This is the most restricted selection criteria of all the scenarios examined in the study. We also considered a version of this scenario that prioritized parcels in socially vulnerable census tracts using the social vulnerability score from the CDC's SVI. We prioritized parcels in census tracts with a social vulnerability index of 0.5 or greater using the Housing and Transportation theme (for more information, see https://svi.cdc.gov/).

Table 2. Summary of Candidate Buyout Selection Criteria.

Scenario	Measures	Description
Current Practice (Existing Requirements in Harris County)	Flooding Source	Riverine flooding
	Repetitive Loss	Whether property loss is repetitive
	Floodplain	Whether property is in the floodplain
Wetlands, Floodplains and Buyouts	SFHA distance	Distance of property to edge of floodplain
	NWI Distance	Distance of property to edge of Wetland
	Buyout Distance	Distance of property to nearest existing buyout
Parks, Protected Areas, and Buyouts	Park distance	Distance of property to parks
	Conservation	Distance of property to conservation east.
	Protected Areas	Distance of property to protected areas
	Buyout Distance	Distance of property to nearest existing buyout
All Natural Features and Buyouts	SFHA distance	Distance of property to edge of floodplain
	NWI Distance	Distance of property to edge of Wetland
	Park distance	Distance of property to parks
	Conservation	Distance of property to conservation east.
	Protected Areas	Distance of property to protected areas
	Buyout Distance	Distance of property to nearest existing buyout

Results

Current Practice

Analysis of existing requirements by HCFCD and FEMA generated 362 available buyouts for flood mitigation. Acquiring these properties would cost $42.69 million based on the appraised market value. The total losses to these properties from Harvey alone was $57.56 million, making the purchase of these properties financially advantageous for just one storm event. Repetitive losses to these properties since NFIP inception totaled $112.77 million, implying a damage to market value ratio of about 2.6. As shown in Figure 6, the spatial pattern of this scenario shows that all candidate buyouts fall within existing floodplains and for the most part in the floodway itself. Under this scenario, 117 acres would be restored back to open space with the candidate properties having an average distance of about 6,300 feet to existing buyout locations (see Figure 5 and Figure 6).

When we further explored this scenario by restricting buyouts to those within 500 feet of all ecological features as well as existing buyouts, only 10 properties are selected as candidates with a damage to market value of about 2.58 (see Figure 7). As shown in Figure 8, the candidate buyouts are mostly concentrated northwest of the I-610 loop in the central Houston area, with a few properties located in the Pasadena and Cloverleaf area of Harris county. This is an extremely conservative buyout selection criterion because it requires that properties meet existing FEMA requirements and must be essentially adjacent to (within 500 feet) of all wetlands, parks and protected areas. Adding this more stringent selection criteria restores only 2.3 acres to open space across 10 properties (see Figure 8).

Wetlands, Floodplains and Buyouts

This scenario prioritizes buyouts that are close to wetlands and floodplains but also considers their distance to properties that have already been bought out for flood mitigation purposes. The first scenario tested a distance threshold of 500 feet and produced 419 candidate buyout properties that collectively incurred approximately $56 million in insured losses during Harvey and have a total market value of about $40 million (see Figure 9). In this scenario, the market value of the properties is also less than the combined Harvey damages and repetitive loss claims (damage-market value ratio is 1.79). About 120 acres are restored to open space with distance to buyouts and wetlands averaging 253 feet and 273 feet respectively. The average distance to floodplain in this scenario is 32 feet and a distance of 2,500 feet to the nearest protected area (see Figure 10).

In the second part of this scenario, we increased the distance to wetlands and floodplains to 1,000 feet, which led to a total of 1,101 candidate buyout properties, the largest number of all the modelled scenarios in this study (see Figure 11). This scenario derived a damage to market value ratio of 1.62, making buyouts of these parcels fiscally viable based on Harvey claims and repetitive flood losses. As expected, the number of buyout properties is greatly increased due to the relaxed distance threshold, representing the largest opportunity to protect ecological services

while mitigating flood impacts. The largest number of candidate buyout parcels are to the north of Houston along Greens Bayou and Cypress Creek (see Figure 12).

Parks, Protected Areas, and Buyouts

This scenario prioritizes buyouts that are in close proximity to parks and protected areas and existing buyouts. We also considered various distance thresholds for this scenario. The first scenario tested a distance threshold of 500 feet for distances to parks, protected areas, and existing buyouts. This resulted in 78 properties eligible for buyouts with a total market value of $7 million and combined Harvey damage and repetitive flood claims of $13 million (see Figure 13 and Figure 14). We also considered a parks and protected areas scenario that does not restrict selection parcels located near other buyouts. This scenario, which kept the distance threshold of 500 feet for parks and protected areas, resulted in a total of 411 candidate properties with a damage to market value ratio of 1.45 (see Figure 15 and Figure 16). We also explored a scenario with a relaxed distance threshold of 1000 feet. For this scenario, 313 parcels within 1,000 ft of existing parks, protected areas, and existing buyouts were selected with a damage to market value of 1.76 (see Figure 17 and Figure 18). When proximity to existing buyouts are not included this scenario, a total of 1,033 properties are eligible for buyouts with a damage to market value ratio of 1.51 and a market value of about $135 million (Figure 19 and Figure 20). Over 700 hundred additional properties are selected when distance to existing buyouts are not included in the selection criteria. In particular, multiple properties adjacent to Addicks and Barker Reservoirs become eligible for buyouts once the proximity to existing acquisitions is listed—an area where several proposals were made to purchase properties following Hurricane Harvey. About 243 acres are restored to open space in the 1,000 feet scenario with distance to buyouts and protected areas averaging about 12,694 feet and 542 feet respectively. Average distance to the nearest FEMA-designated 100-year floodplain in this scenario is 448 feet.

All Natural Features and Buyouts

This scenario prioritizes buyouts that are in close proximity to wetlands, floodplains, parks, protected areas and buyouts. The first scenario (Figure 21 and Figure 22) used a distance threshold of 500 feet and resulted in a total of 67 properties selected for buyouts with a total market value of $5.82 million. Buyouts in this scenario are financially beneficial, with insured losses amounted to almost $10 million resulting in a DMVR of 1.69. Approximately 16.5 acres are restored under this scenario. Increasing the distance to natural features and existing buyouts to 1,000 ft generated a total of 290 candidate properties as seen in Figure 23 and Figure 24. This scenario also results in the restoration of about 290 acres to open spaces and a damage to market value ratio of 1.8. Finally, we considered an additional scenario where buyouts are restricted to properties located in a census tract with a Social Vulnerability Index score of at least 0.5. This scenario selects 192 properties with 39 acres restored back to open space (see Figure 25 and Figure 26). For this scenario, the damage to market value ratio is higher than those without considerations for social vulnerability with a total value of 2.12.

Discussion of Scenario Results

As shown in Table 3Table 1, the Current Practice focused on the existing Harris County and FEMA requirements generates the highest damage to market value ratio, with a value of 2.67. A major reason for this high cost-benefit ratio is because this scenario considers properties with repetitive flood claims, a major selection criterion for receiving federal funding for buyouts. This scenario also has the greatest number of properties that have experienced repetitive flooding with over $56 million in repetitive flood claims.

In contrast, the 'Parks, Protected Areas and Buyouts' scenario, despite being cost-effective, has the least benefit from an economic perspective with a damage to market value ratio of just 1.51. However, this scenario identifies over 1,000 properties as candidate parcels for buyouts. Similarly, the scenario which prioritizes proximity to floodplains and wetlands generates about 1,100 properties as candidate buyouts with a damage to market value ratio of about 1.6. The final scenario examined, which prioritizes proximity to natural features and buyouts but is restricted to socially vulnerable communities, results in over 190 properties for potential acquisition and produced the third highest damage to market value ratio of 2.12. This result is not surprising because communities with high housing social vulnerability are frequently have less expensive and lower quality housing, making buyouts more economically feasible in many of these locations.

Table 3. Summary of Buyout Scenarios.

			Millions of dollars				
Scenario	**Distances (ft)**	**No of Properties**	**Harvey Damages**	**Rep Claims**	**Harvey +Rep Loss**	**Market Value**	**DMVR**
Current Practice	Variable	362	57.56	56.21	113.77	42.69	**2.67**
	Variable + 500 ft all ecological	10	1.88	1.66	3.54	1.37	**2.58**
Wetlands, Floodplains and Buyouts	500	419	56.37	16.57	72.94	40.85	**1.79**
	1,000	1101	156.72	29.44	186.16	114.62	**1.62**
Parks, Protected Areas and Buyouts	500	78	10.88	2.00	12.88	7.64	**1.69**
	500, No BO distance	411	76.79	7.03	83.82	57.73	**1.45**
	1,000	313	39.50	7.24	46.74	26.59	**1.76**
	1,000, No BO distance	1033	181.02	22.79	203.81	135.06	**1.51**
All Natural Features and Buyouts	500	67	8.20	1.66	9.86	5.82	**1.69**
	1,000	290	36.9	7.13	44.03	24.39	**1.81**
	1,000 + SVI $\geq$ 0.5	192	23.68	6.27	29.95	14.16	**2.12**

A shown in Table 4, the various scenarios result in different configurations of open space given varying proximities to natural features and existing buyouts. The 'Wetlands, Floodplains and Buyouts' scenario, for example, resulted in the most acreage restored to open space (about 295 acres) while the "Current Practice" scenario restricted to a proximity requirement of within 500 feet of natural features results in only about 2 acres restored to open space. It is important to note

that several scenarios that prioritize proximity to natural areas and existing buyouts (unlike the existing current practice) have lower mean distances to parks, existing buyouts and wetlands, all of which are likely to reduce "checker-boards" of buyouts that are frequently encountered. The Parks, and Protected Areas do not consider proximity to existing buyouts but instead focus on proximity to other ecological features. This can be seen from several buyout candidates near the Addicks and Barker reservoirs/park.

Table 4. Summary of Distances to Ecological Features.

		Average Distance to feature (feet)						
Scenario	**No. of Properties**	**Buyouts**	**Parks**	**SFHA**	**Wetlands**	**Protected areas**	**Acreage restored**	**Acres Per Property**
Current Practice	362	6,375.34	1,862.27	0	472.74	2,408.27	**117.47**	**0.32**
+500' from all ecological	10	135.58	248.51	0	263.89	216.17	**2.37**	**0.24**
Wetlands, Floodplains and Buyouts	419	253.35	1,758.29	32.20	273.73	2,533.01	**120.77**	**0.29**
	1101	444.81	1,801.71	57.60	446.09	2,342.77	**295.17**	**0.27**
Parks, Protected Areas and Buyouts	78	214.36	292.01	54.74	383.96	299.61	**19.82**	**0.25**
	411	14,073.18	252.60	360.33	492.30	267.13	**95.31**	**0.23**
	313	377.58	559.08	75.32	512.74	567.51	**70.82**	**0.23**
	1033	12694.34	497.60	448.50	566.85	542.27	**243.49**	**0.24**
All Natural Features and Buyouts	67	203.10	286.11	38.98	312.48	287.53	**16.53**	**0.25**
	290	351.62	555.70	65.50	450.73	561.44	**67.05**	**0.23**
	192	338.35	550.98	57.92	481.92	547.80	**38.78**	**0.20**

The results of each scenario vary based on the degree to which proximity to natural features and buyouts are emphasized in the selection process. While it is ultimately up to decision makers to decide which approach to take when constructing a buyout program, our eleven scenarios provide an important first step for those communities interested in developing buy out programs with multiple economic, social, and environmental benefits.

Conclusion

Flood risk and exposure in urban areas is expected to increase due to rapid population growth and development (Brody et al. 2008), increasing the need for strategic solutions. This project focused on creating a framework for identifying flood-prone candidate parcels for acquisition in Harris County, TX. Results show that the buyouts remain cost effective, even when proximity to other buyout parcels and existing open space are included in the selection process. The addition of these criteria does not undermine the overall cost effectiveness of property acquisition as a tool to promote flood resiliency, and creates green spaces that add multiple values. Overall, our analysis identified between 10 to 1,100 properties with a positive damage to market value ratio and a total market value ranging from $1.37 to $135.06 million. Our multi-distance ecological

selection criterion resulted in the possibility of restoring between 2 to 295 acres back to open space in Harris County.

While this project highlights the importance of identifying high risk properties, it also emphasizes the importance of prioritizing clustering of buyouts and proximity to existing parks and open spaces. Smart public policy actions can help translate this study into strategic buyout programs in Harris County and communities across the United States. Financial incentives are needed to encourage landowners to participate in strategic, more clustered buyouts. Already in Harris County, voters overwhelmingly (by over 85 percent) approved a $2.5 billion flood mitigation bond proposition in August 2018 to support projects like voluntary buyouts of flood-prone properties and property acquisition for preserving natural floodplains. Other successful buyout programs, such as New York Rising and New Jersey Blue Acres, recognized the disadvantages of checkerboard buyouts and incentivized large housing blocks to volunteer their property for acquisition after a flood event. However, acquiring flood-prone properties is just the first step—successful and transformative property acquisition programs also need to allocate funds to facilitate property restoration, including structure removal and replanting lands to appropriate vegetation cover. Once acquired and returned to a natural state, a funded management system is needed to retain a clean and safe park-like environment. The Nature Conservancy is currently advancing projects that restore and manage flood-prone properties for the benefit of local communities in Austin and Houston, Texas. These examples demonstrate how communities can begin to rethink the use of urban open space for multiple benefits, including flood risk reduction and the creation of urban parks.

Future Research

This study represents just a first step in examining the importance of open space protection and land acquisition for flood risk reduction. Additional research and data analytics should be conducted to address some of the limitations of our study and further this strategic area of inquiry. First, this study only assesses one storm event. While Hurricane Harvey was an unprecedented event for coastal Texas, future work should consider historic patterns of flood loss coupled with probabilistic measures of future flood risk. Second, we only conduct buyout scenarios for one county in Texas. Additional research should expand to a broader geographic scope and include other jurisdictions both within Texas and across the U.S. Such an approach would provide a larger sample of parcels from which to make conclusions and add a comparative component to the analyses. Finally, our study did not consider the additional floodwater storage capacity that acquired properties may provide. Future research should incorporate hydrologic and hydraulic modeling to quantify the flood mitigation benefits of converting acquired property to

open space. Future studies should also explore how the various configurations of buyouts, once converted to open space, may perform as natural infrastructure to collect and store stormwater runoff.

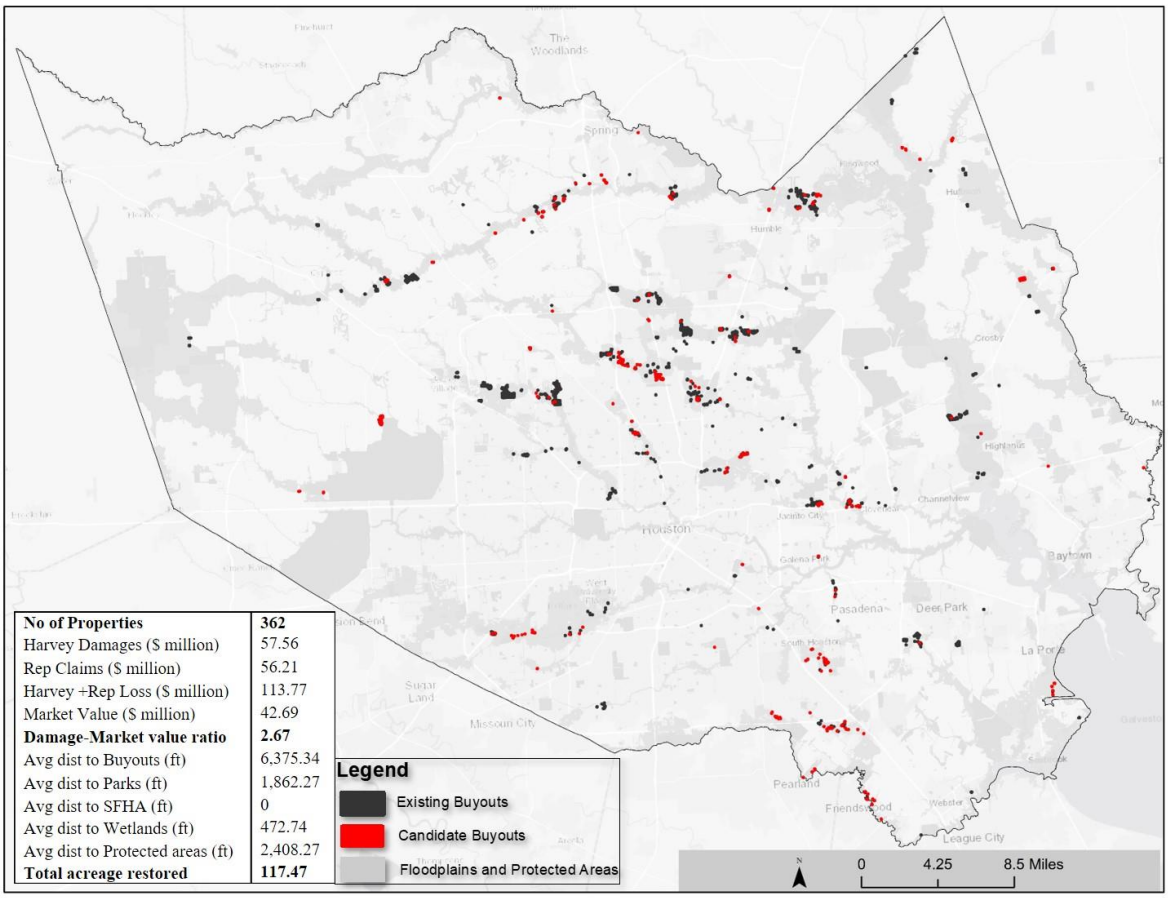

Figure 5. Candidate Buyouts selected using existing Harris County buyout requirements.

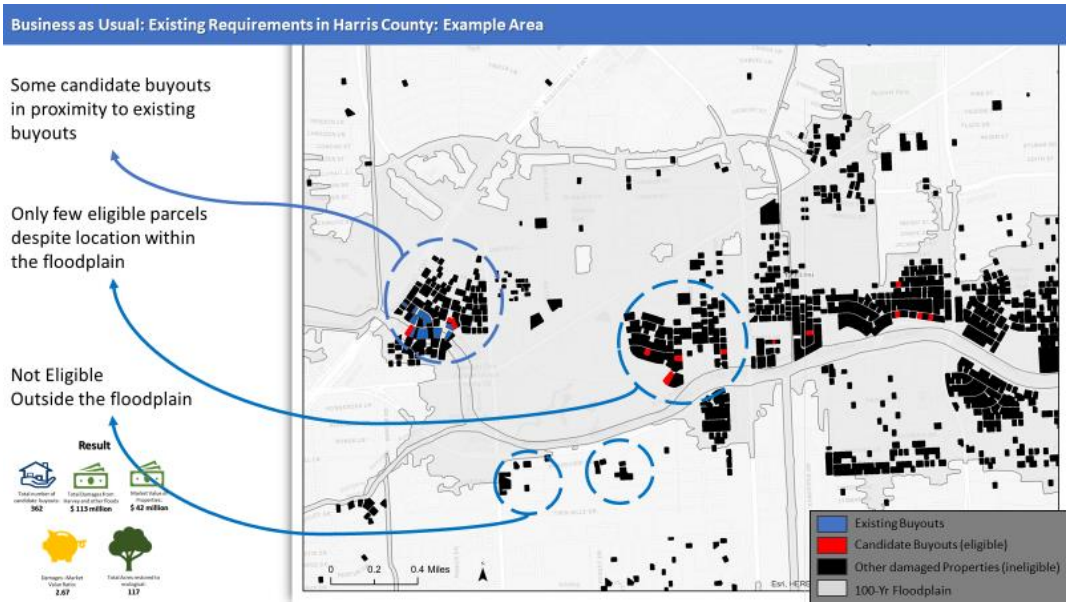

Figure 6. Sample of candidate buyouts using existing Harris County buyout requirements.

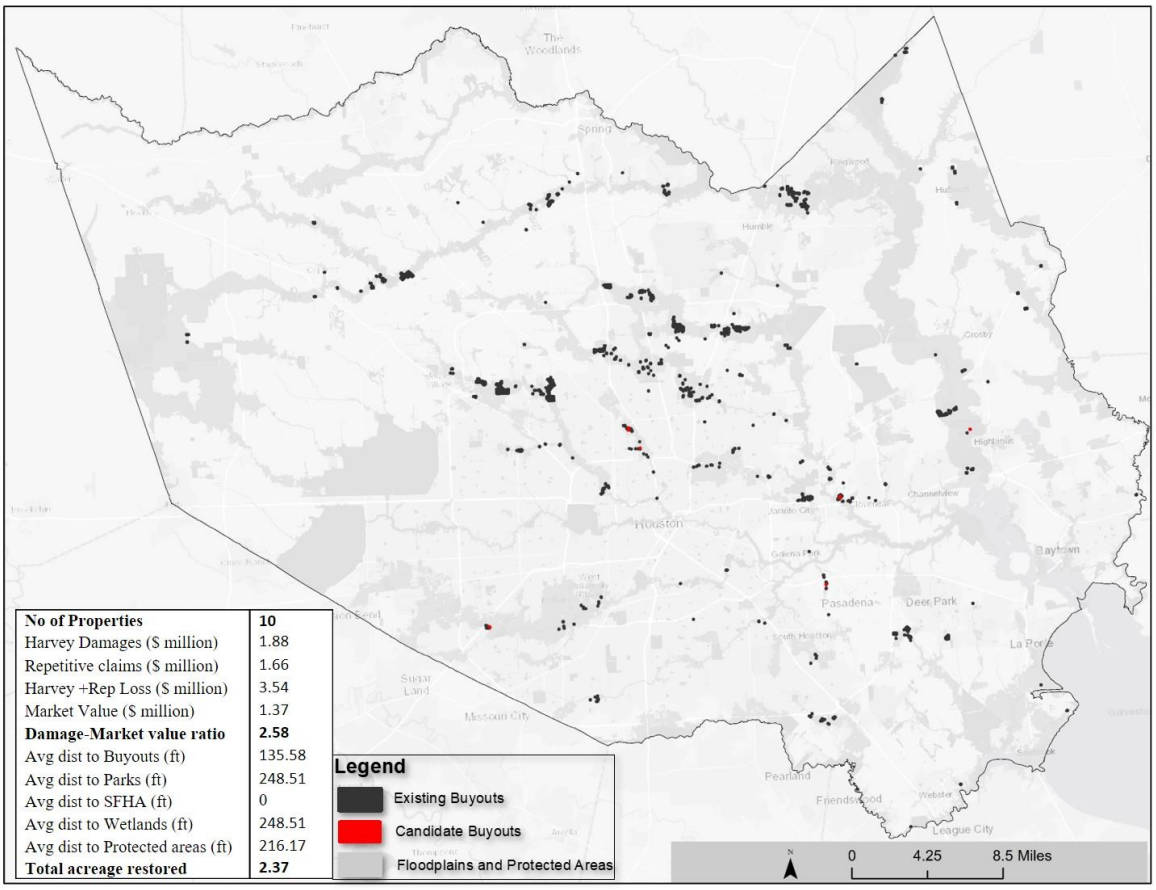

Figure 7. Candidate buyouts based on existing Harris County requirements with additional 500 ft restrictions to wetlands, parks and protected areas.

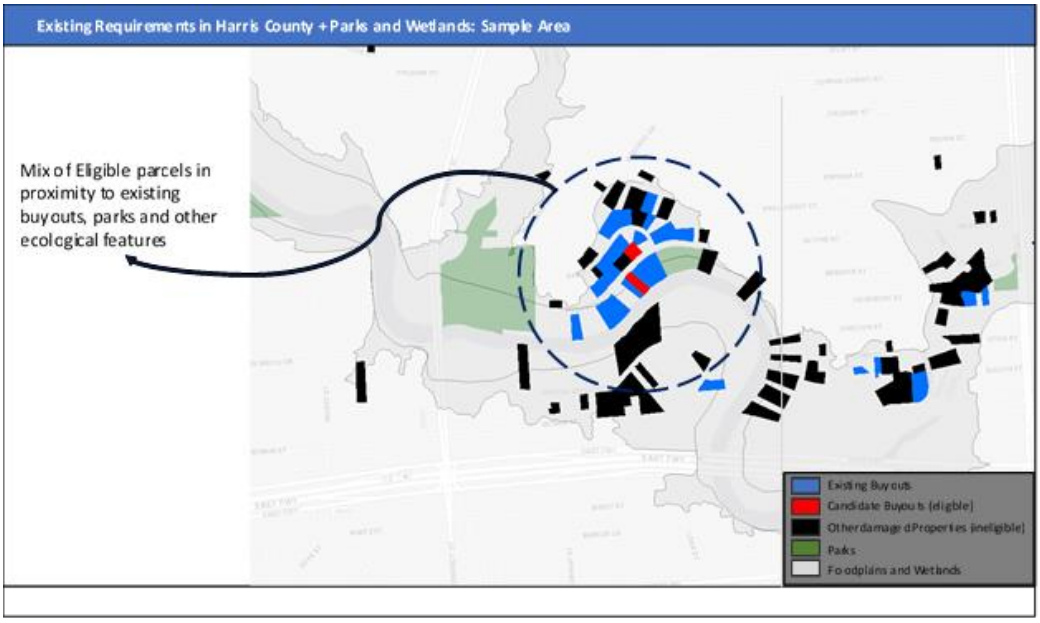

Figure 8. Sample of candidate buyouts based on existing Harris County requirements with additional 500 ft restrictions to wetlands, parks and protected areas.

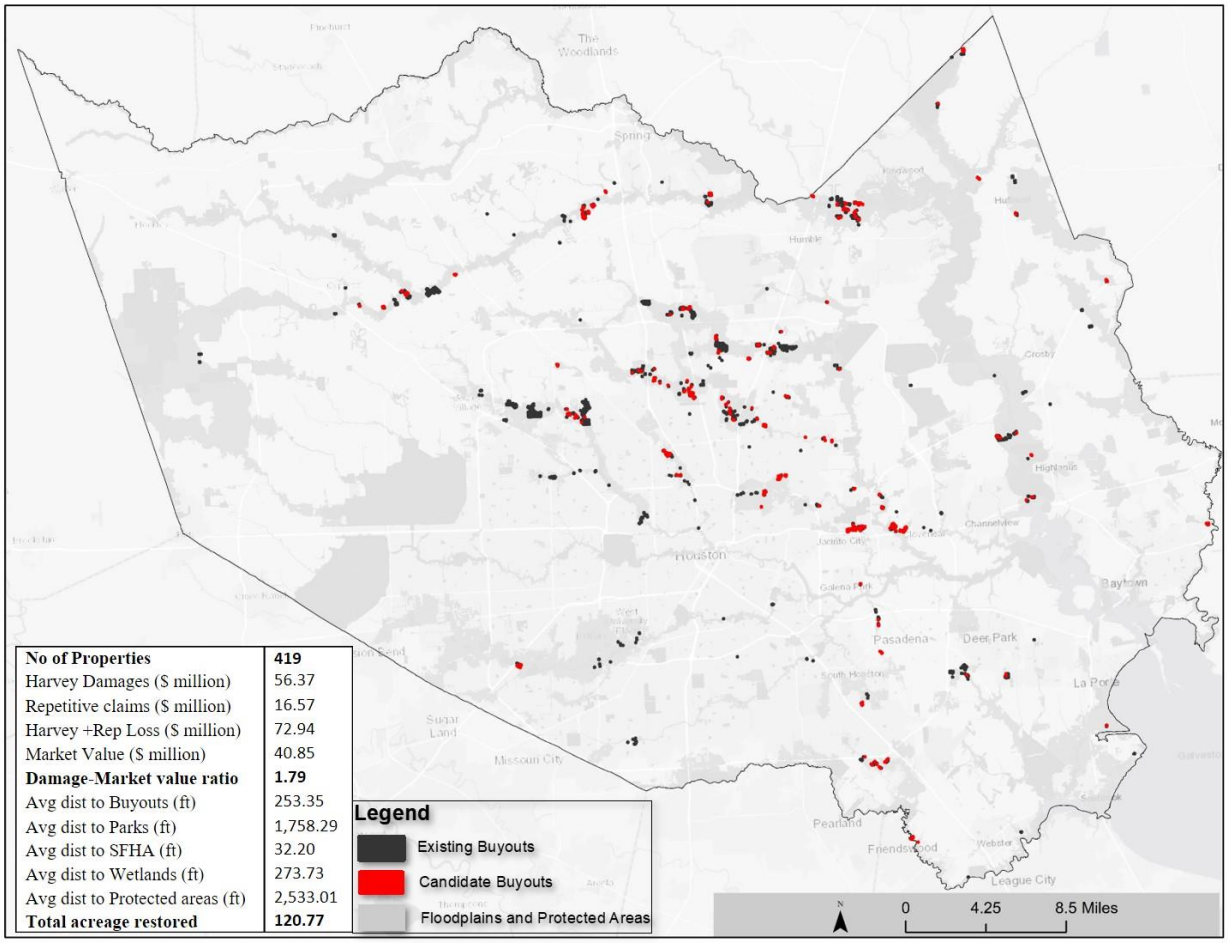

Figure 9. Candidate buyouts within 500 ft of wetlands and floodplains.

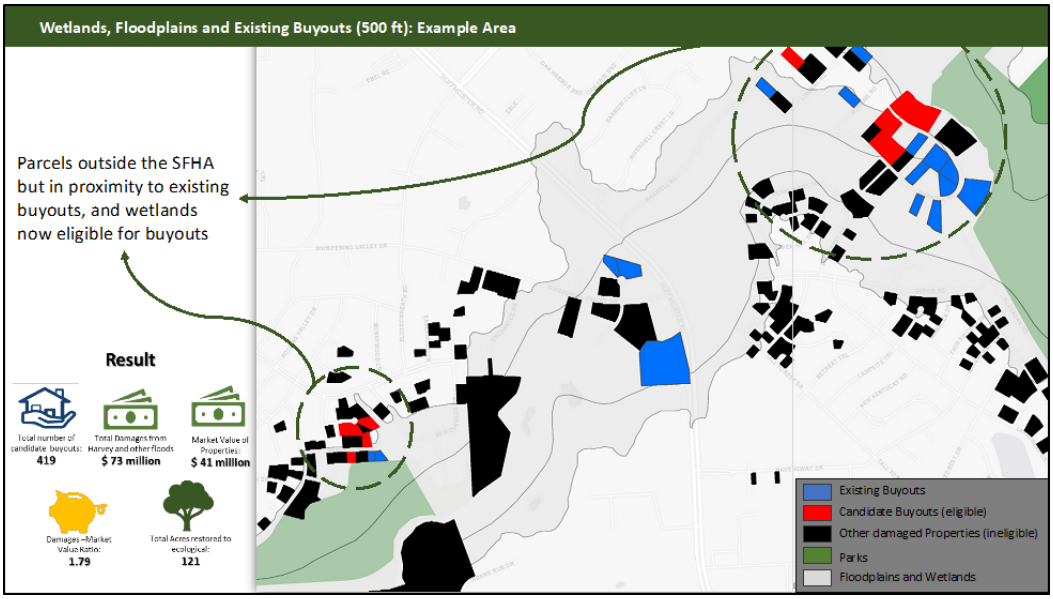

Figure 10. Sample of candidate buyouts within 500 ft of wetlands and floodplains.

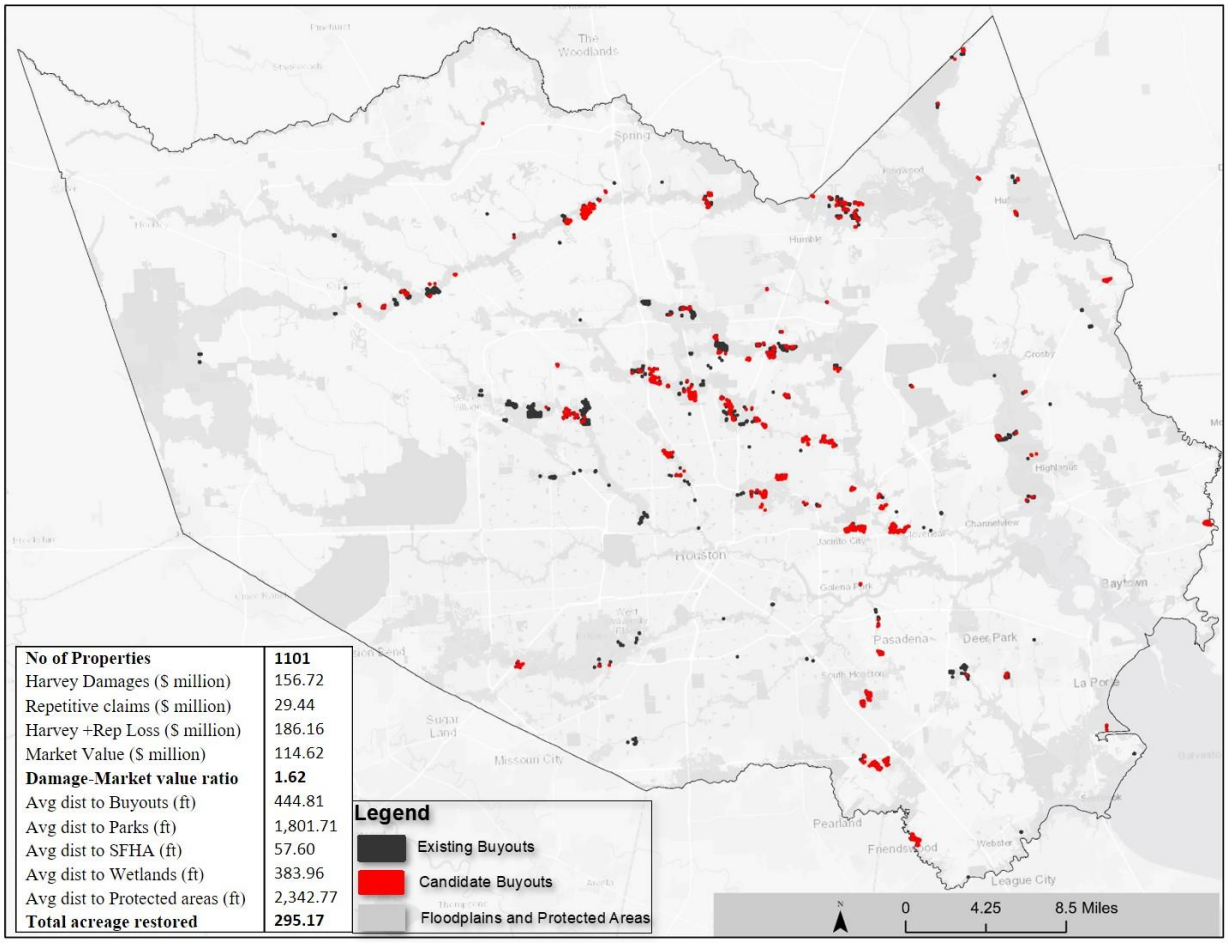

Figure 11. Candidate buyouts within 1,000 ft of wetlands and floodplains.

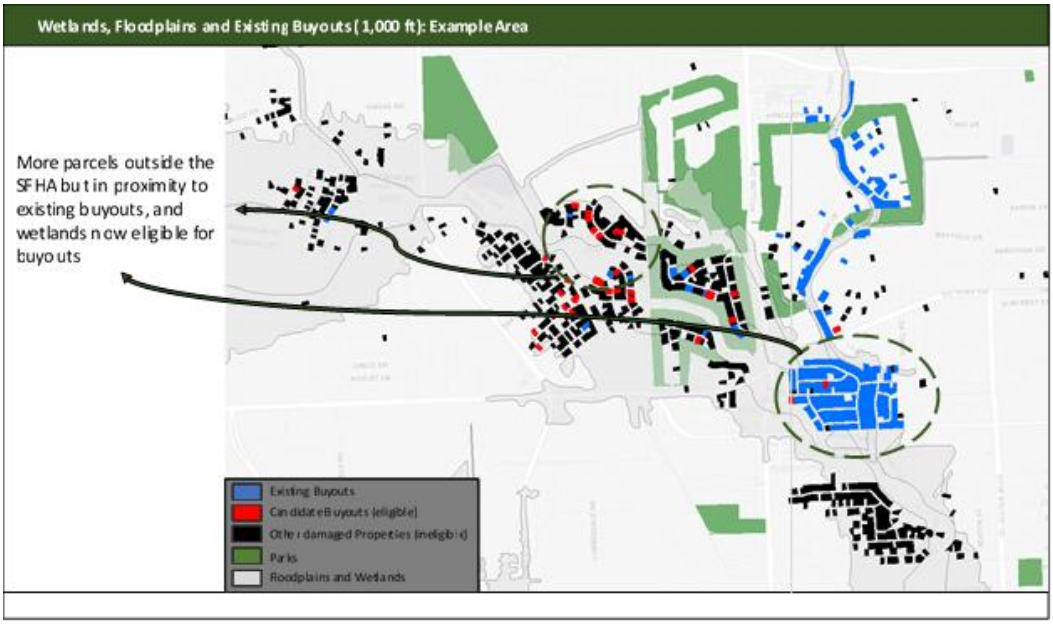

Figure 12. Sample of candidate buyouts within 1,000 ft of wetlands and floodplains.

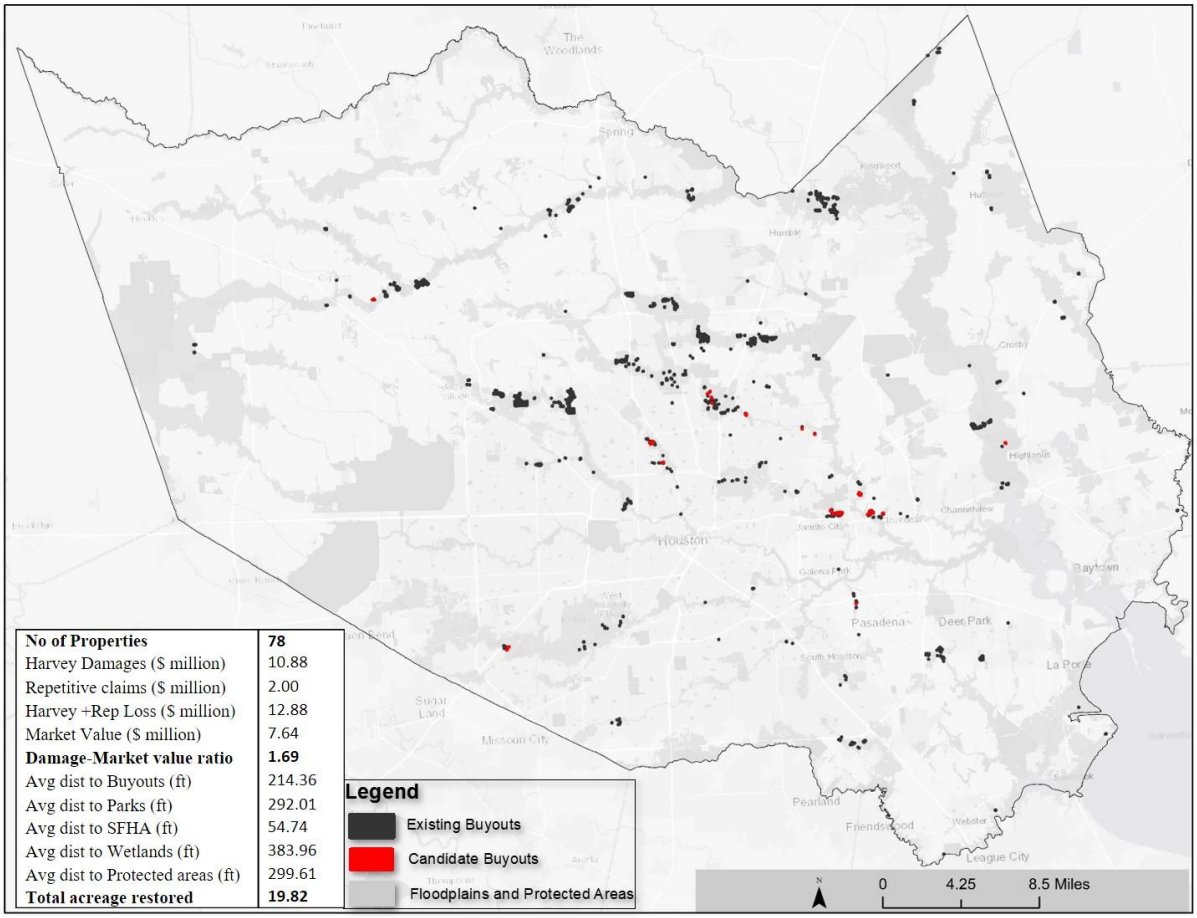

Figure 13. Candidate buyouts within 500 ft of parks, protected areas, and existing buyouts.

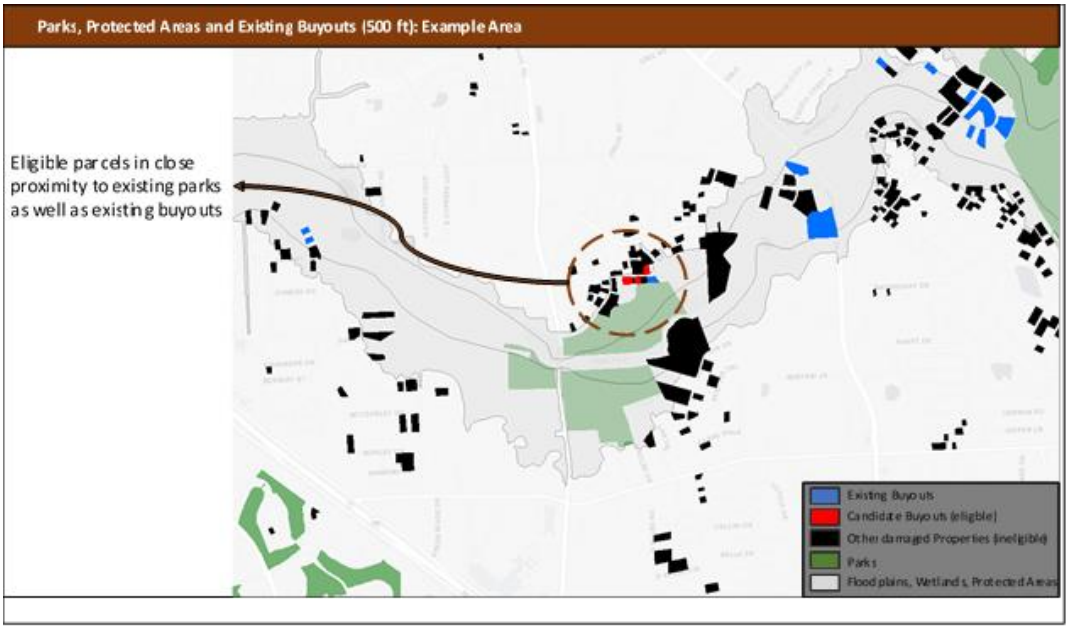

Figure 14. Sample candidate buyouts within 500 ft of parks, protected areas, and existing buyouts.

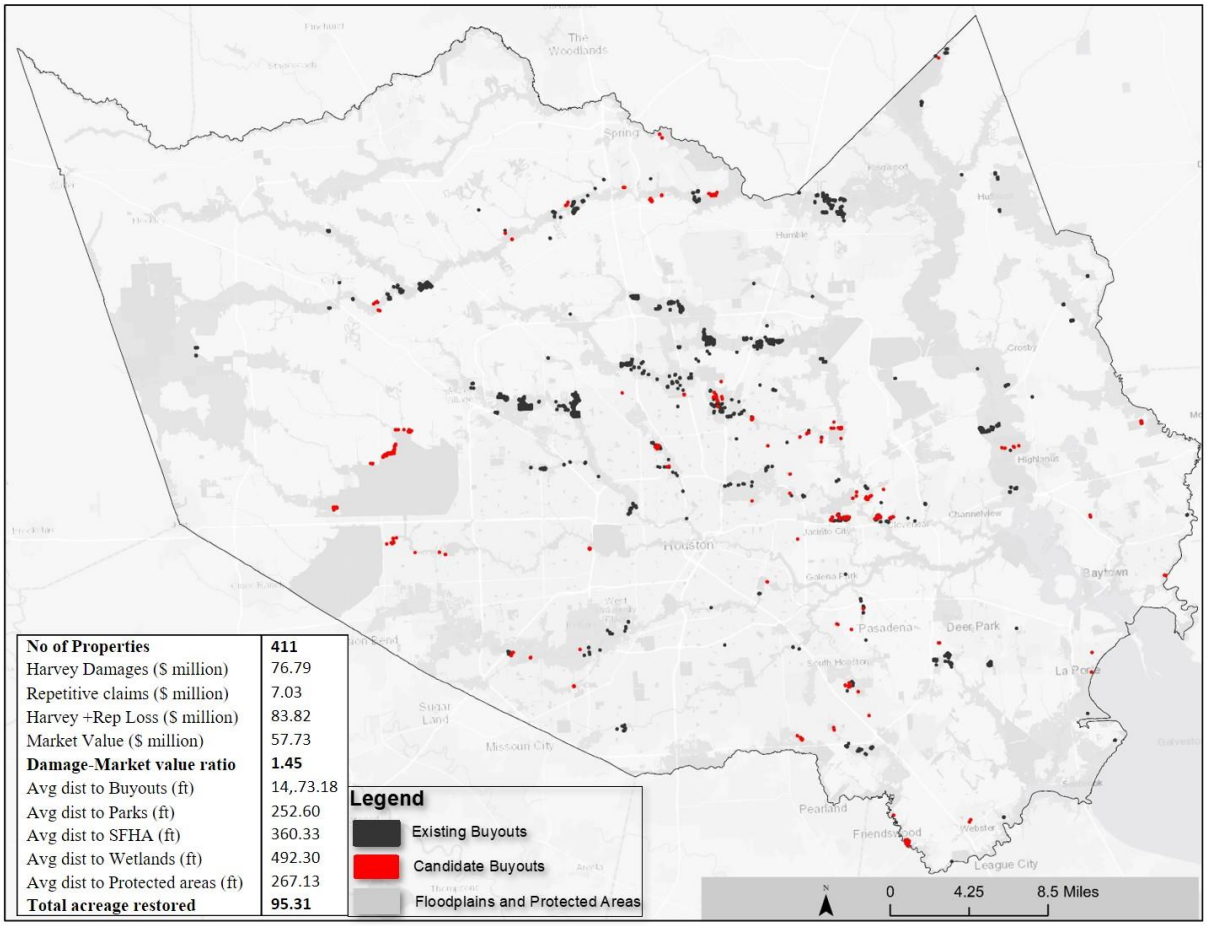

Figure 15. Candidate buyouts within 500 ft of parks, and protected areas excluding buyouts.

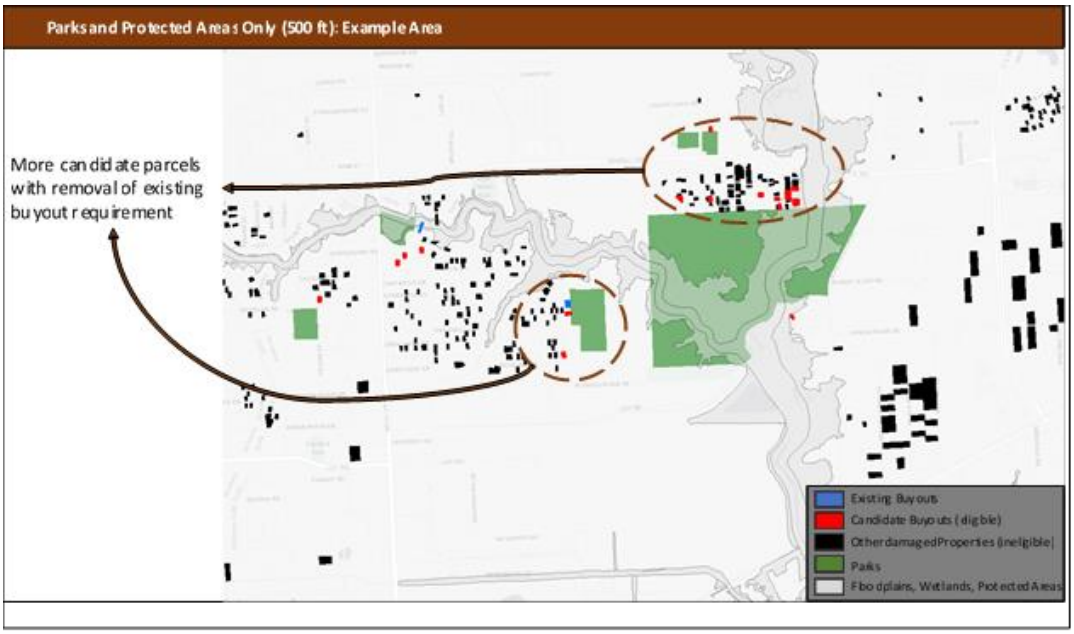

Figure 16. Sample candidate buyouts within 500 ft of parks, and protected areas excluding buyouts.

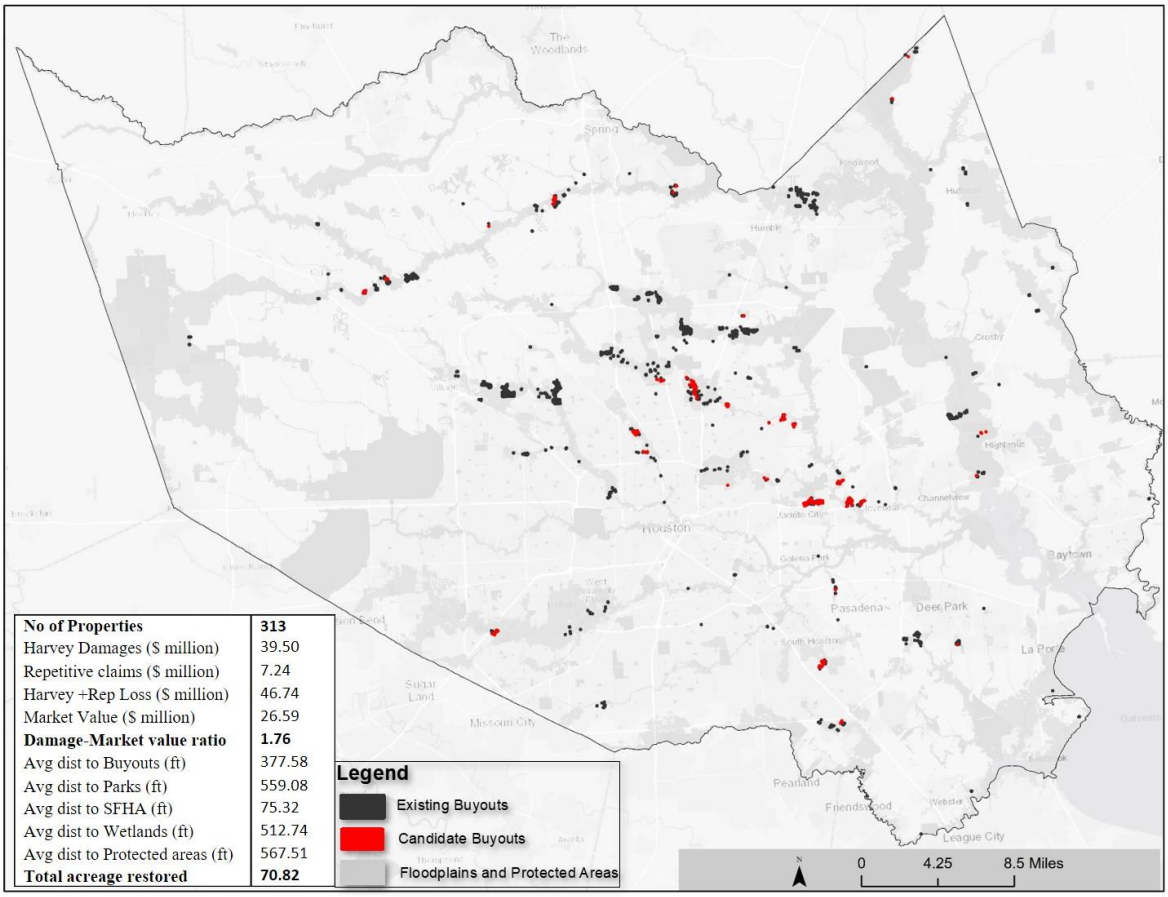

Figure 17. Candidate buyouts within 1,000 ft of parks, protected areas and existing buyouts.

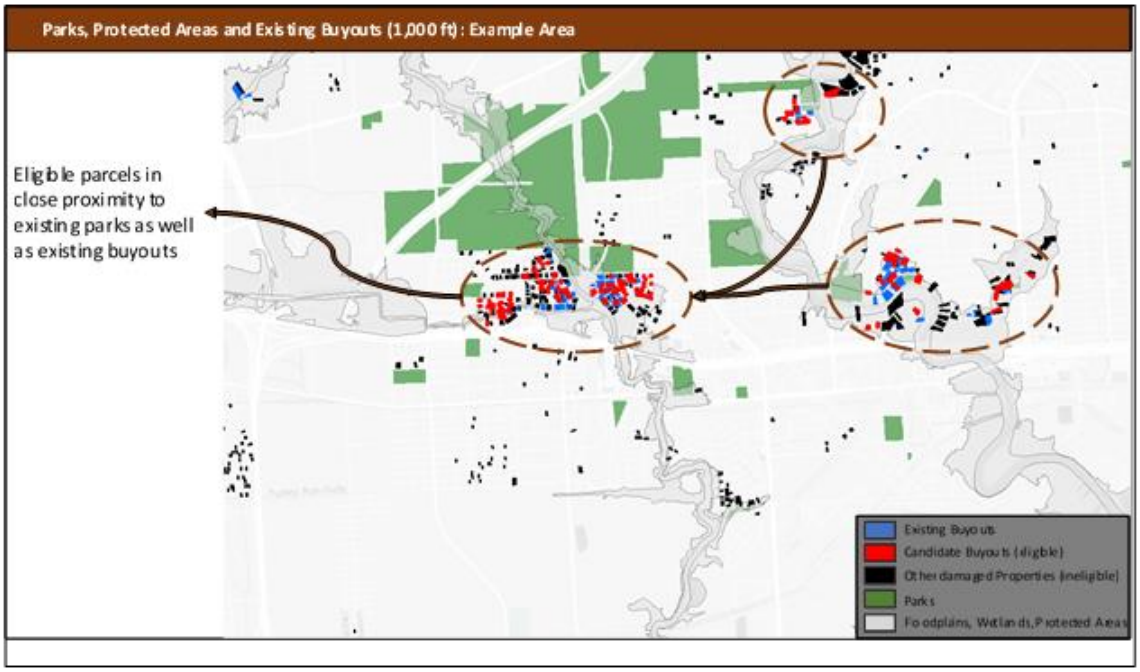

Figure 18. Sample candidate buyouts within 1,000 ft of parks, protected areas and existing buyouts.

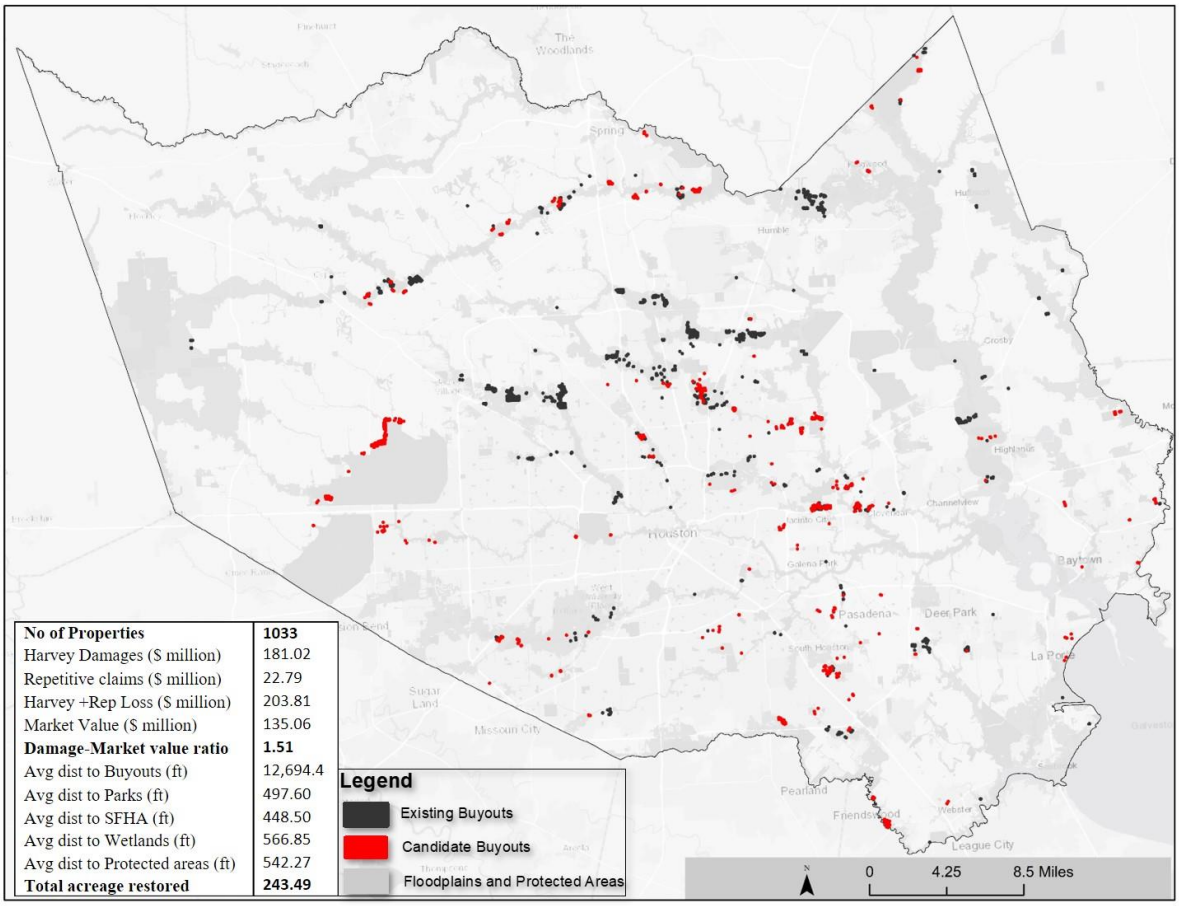

Figure 19. Candidate buyouts within 1,000 ft of parks and protected areas excluding existing buyouts.

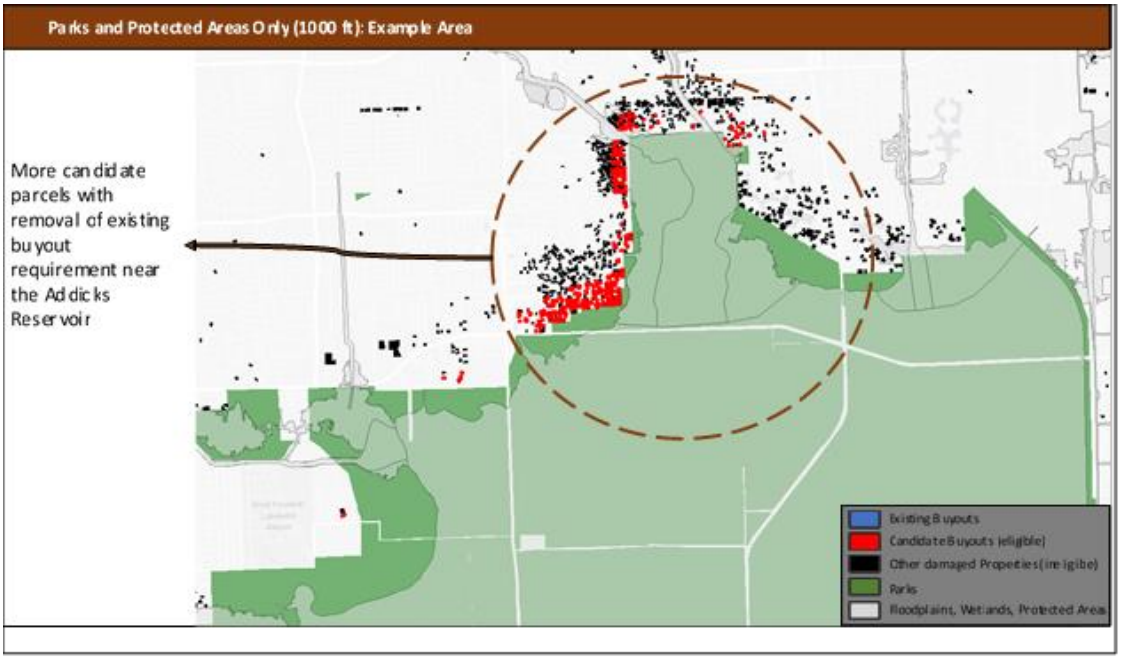

Figure 20. Sample candidate buyouts within 1,000 ft of parks and protected areas excluding existing buyouts.

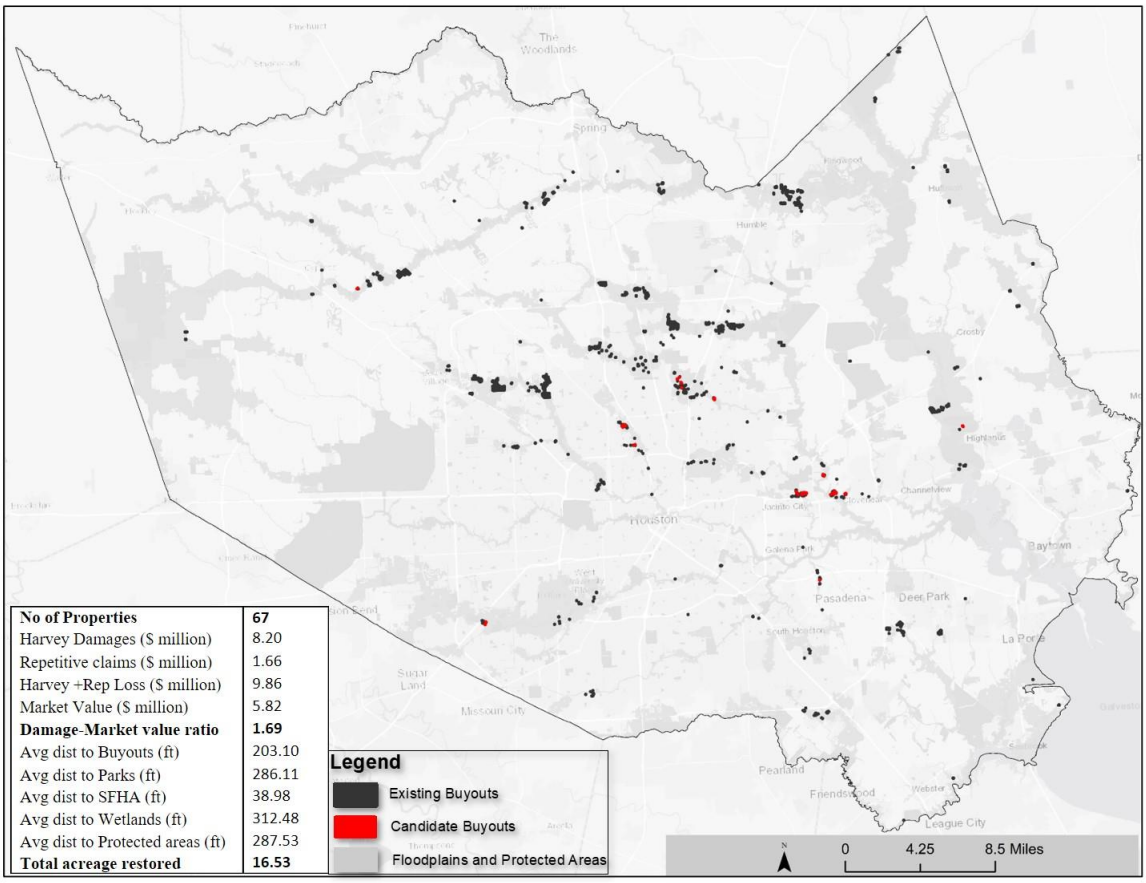

Figure 21. Candidate buyouts within 500 ft of wetlands, floodplains, parks, protected areas, and existing buyouts.

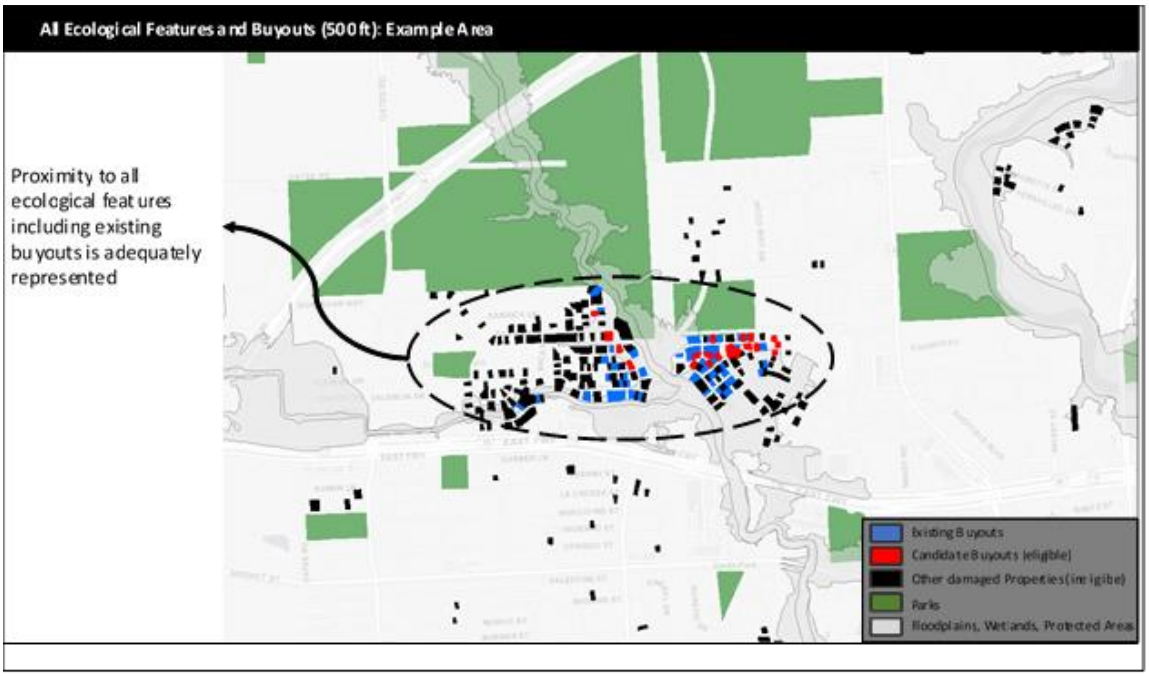

Figure 22. Sample candidate buyouts within 500 ft of wetlands, floodplains, parks, protected areas, and existing buyouts.

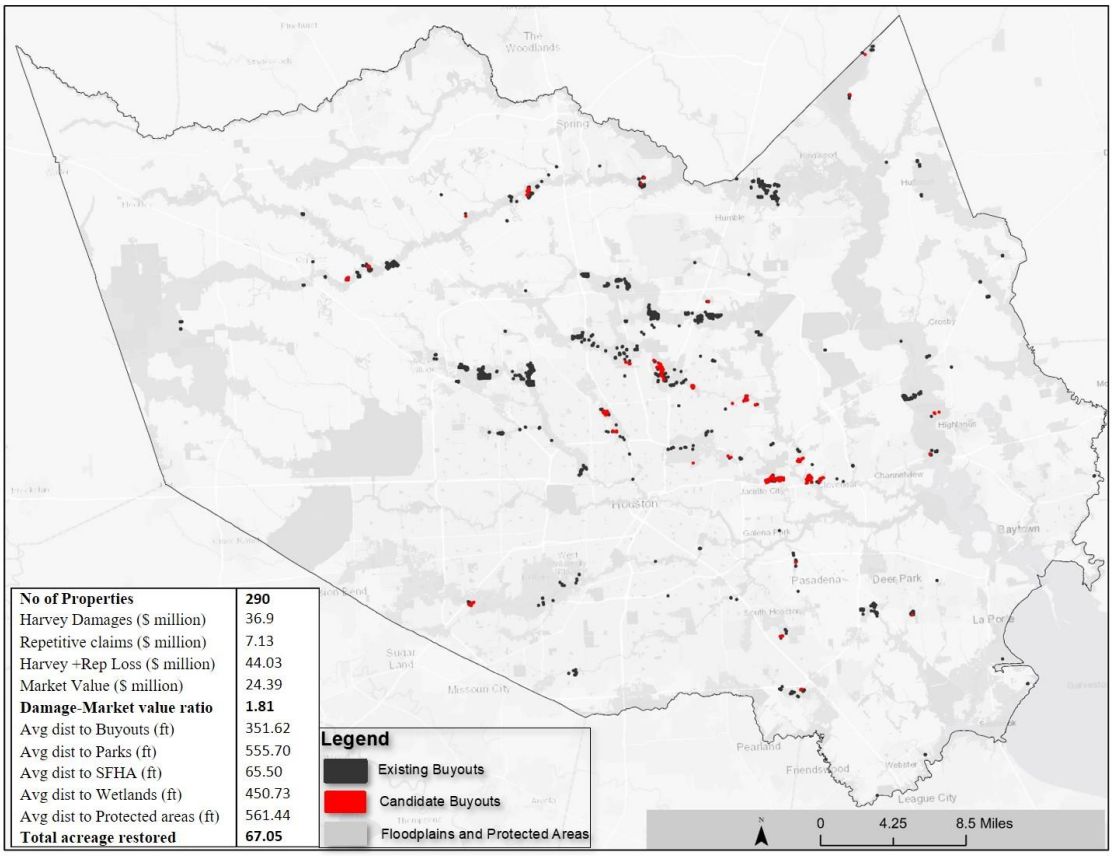

Figure 23. Candidate buyouts within 1,000 ft of wetlands, floodplains, parks, protected areas, and existing buyouts.

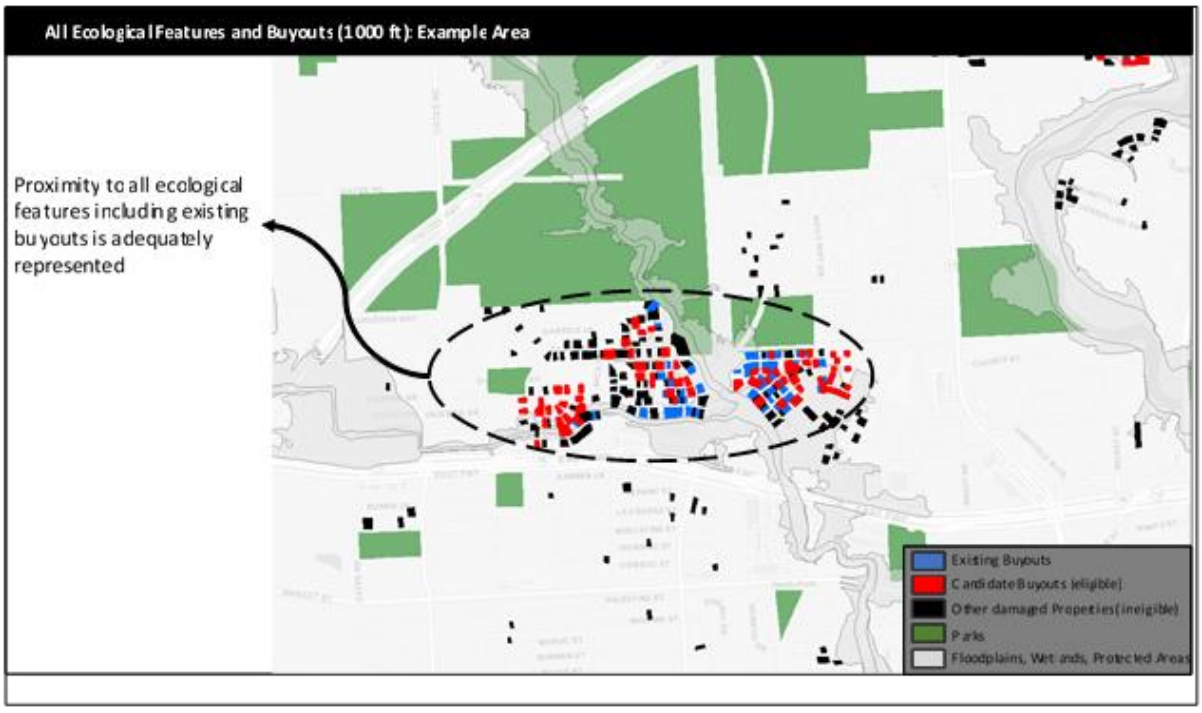

Figure 24. Sample candidate buyouts within 1,000 ft of wetlands, floodplains, parks, protected areas, and existing buyouts.

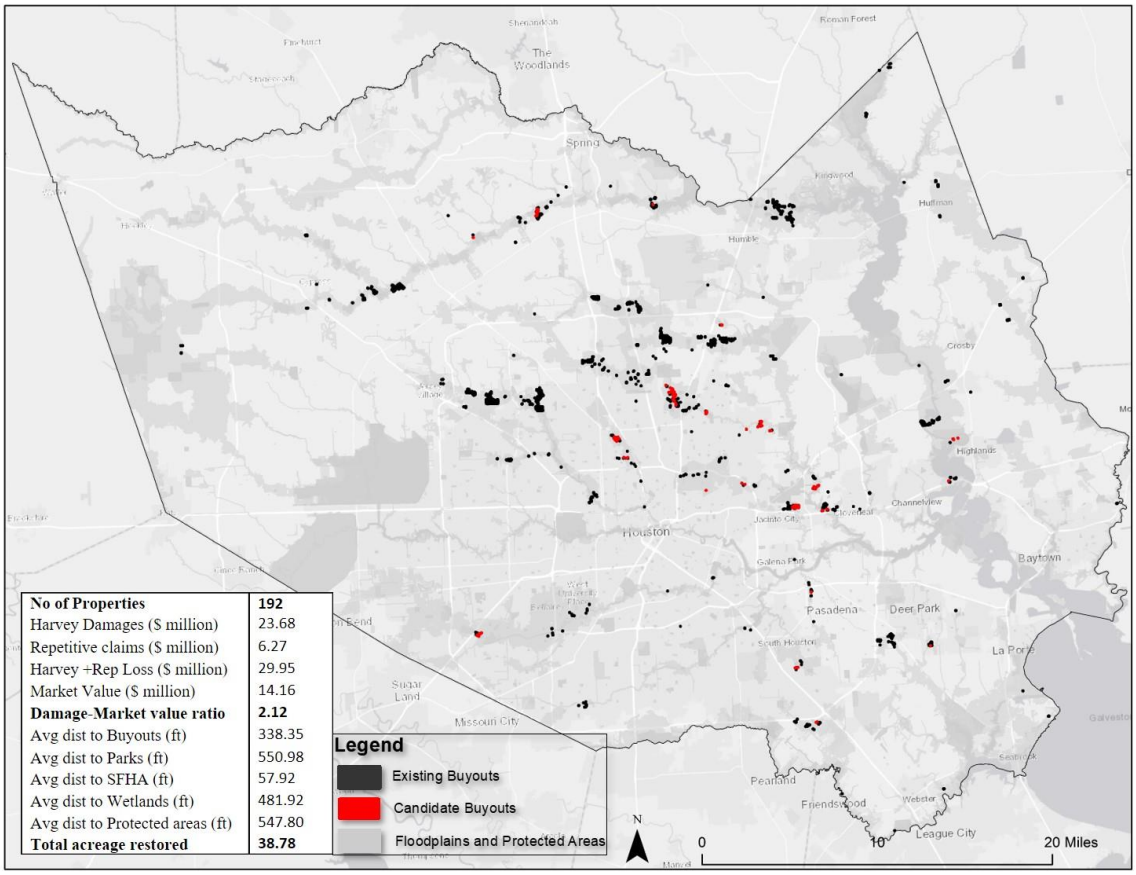

Figure 25. Candidate buyouts within 1,000 ft of wetlands, floodplains, parks, protected areas, existing buyouts, and at least 0.5 SVI score.

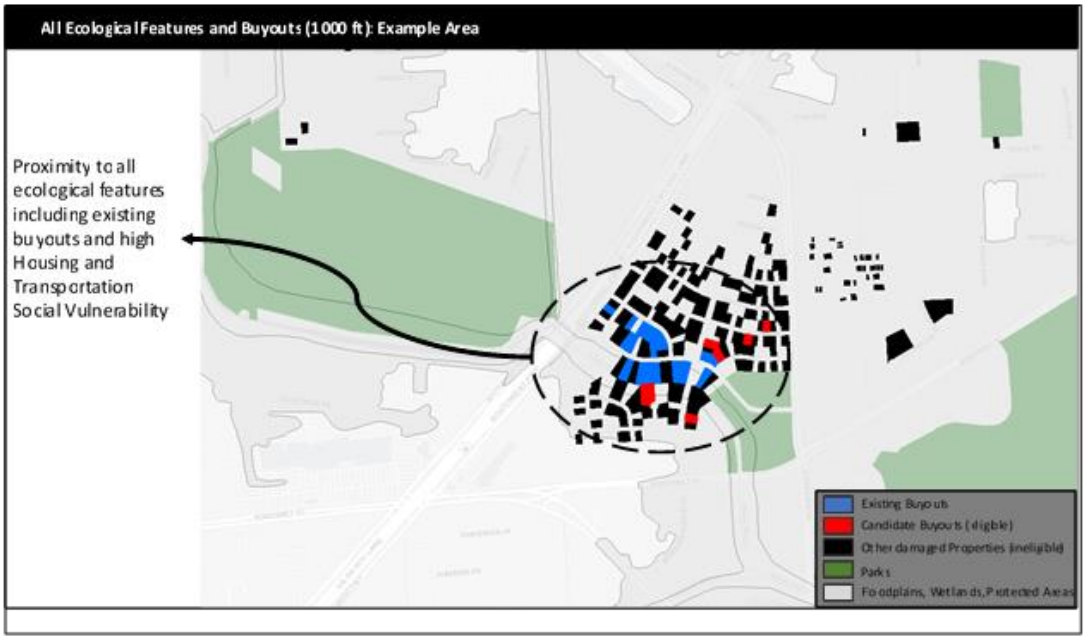

Figure 26. Sample candidate buyouts within 1,000 ft of wetlands, floodplains, parks, protected areas, existing buyouts, and at least 0.5 SVI score.

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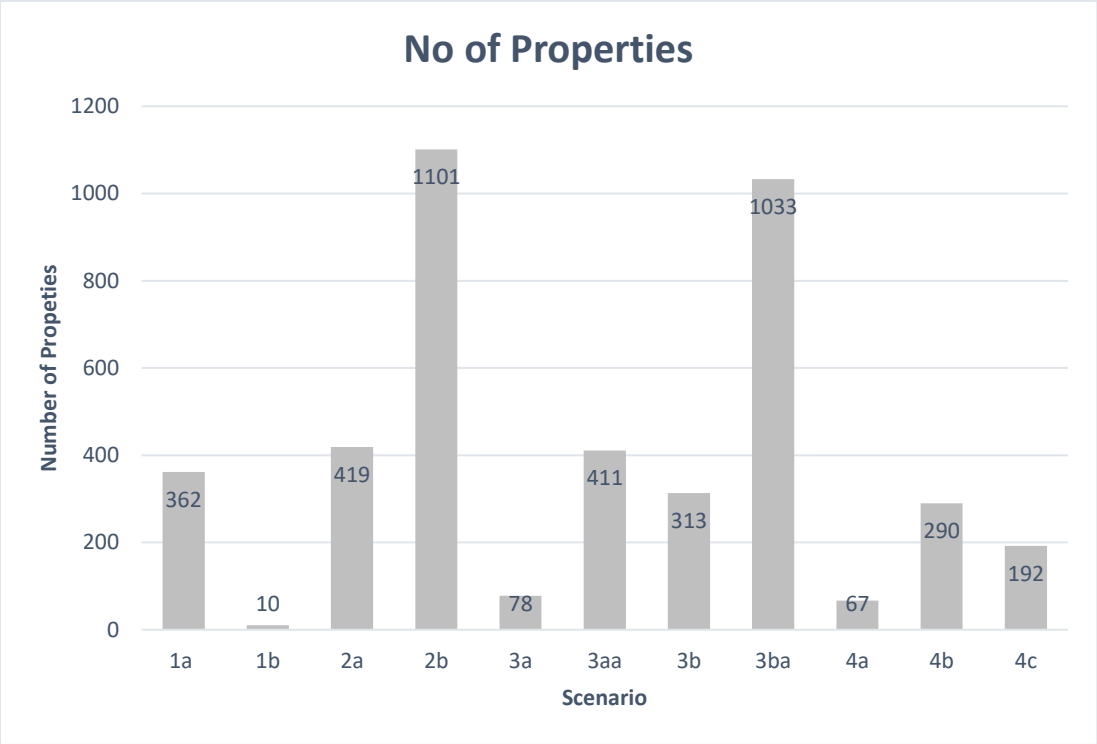
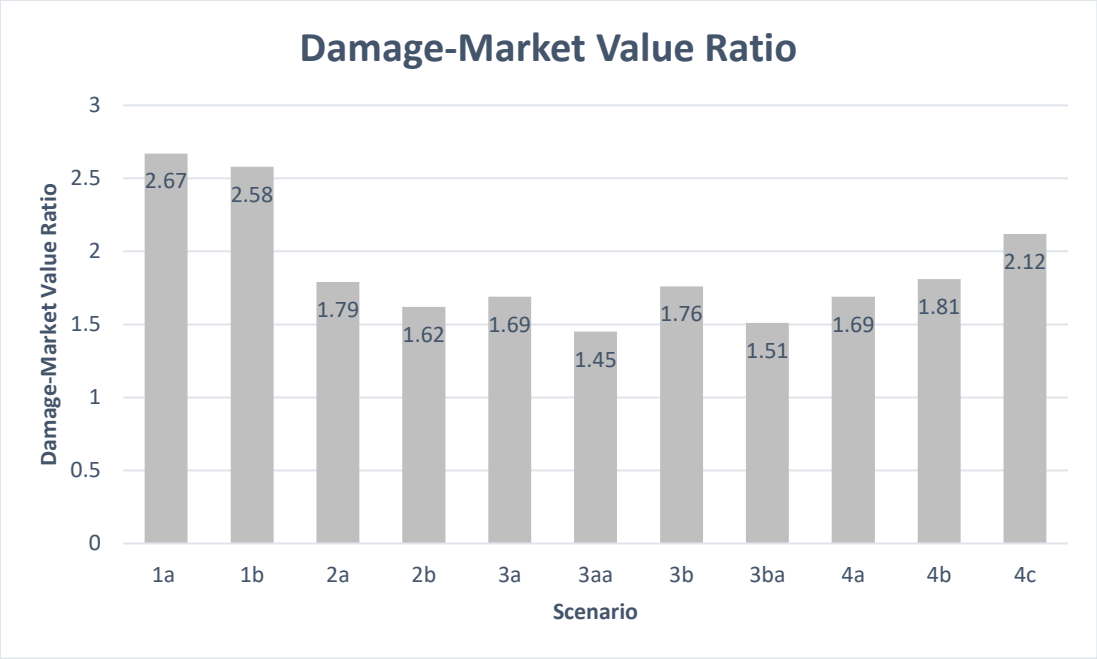
Appendix 1: Data Description

Field	Description	Type	Data source
Building Characteristics			
Name	Parcel ID from HCAD	String	HCAD
Parcel_ID	Parcels ID from HCAD (Duplicate for joins)		
Occupancy	Occupancy code of building	String	HCAD
Cost	Improvement value of structure on parcel	Ratio	HCAD
LandValue	Value of land where building is located	Ratio	HCAD
ContentCost	Cost of content of building	Ratio	HCAD/2
Market_val	Appraised value of parcel	Ratio	HCAD
YearBuilt	Year where property was built	Ratio	HCAD
Area	Square footage of building on parcel	Ratio	HCAD
NumStories	Number of stories of building	Ratio	HCAD
Longitude	X location of parcel	Ratio	HCAD
Latitude	Y location of parcel	Ratio	HCAD
FoundationType	Type of foundation of building	String	HCAD
BldgType	Exterior finish of structure	String	HCAD
DesignLevel	Building before or after NFIP	String	HCAD
FirstFloorHt	First floor elevation	String	Hazus
Bldg_Qty	Quality of structure	String	HCAD
FldZone	Flood zone of building	String	FEMA
Bldg_num	Number of buildings or account in parcel	Ratio	HCAD
BldgDamageFnld	Building Damage curve	String	Hazus
ContDamageFnld	Content Damage curve	String	Hazus
InvDamageFnld	Inventory Damage Curve	String	Hazus
FloodProte	Flood Protection	String	Hazus
Ecological/Environmental Characteristics			
Park_dist	Distance of property to nearest park	Ratio	HGAC
Strm_dist	Distance of property to nearest stream or flowline		
NCED_dist	Distance to National Conservation Easement Database	Ratio	NCED
PADUS_dist	Distance to Protected Area Dataset of the US	Ratio	PADUS
Riprn_dist	Distance to Proposed Riparian Parks	Ratio	RCP/TNC
Prare_dist	Distance to Proposed Prairie Parks	Ratio	RCP/TNC
Oyst_dist	Distance to Proposed Oyster Parks	Ratio	RCP/TNC
NWI_dist	Distance of property to edge of Wetland	Ratio	NWI
SFHA_dist	Distance of property to edge of SFHA	Ratio	GIS
NWI	Whether property is in a wetland	Binary	NWI
NWI_type	Type of nearest wetland	String	NWI
SFHA	Whether property is in the floodplain	Binary	FEMA
SFHA_zn	Which zone property is	Text	Claims
Social Vulnerability (Census Tract)			
SVI_1	Socioeconomic	Ratio	CDC
SVI_2	Household Composition and Disability	Ratio	CDC
SVI_3	Minority Status & Language	Ratio	CDC
SVI_4	Housing & Transportation	Ratio	CDC
SVI_all	Combined index	Ratio	CDC

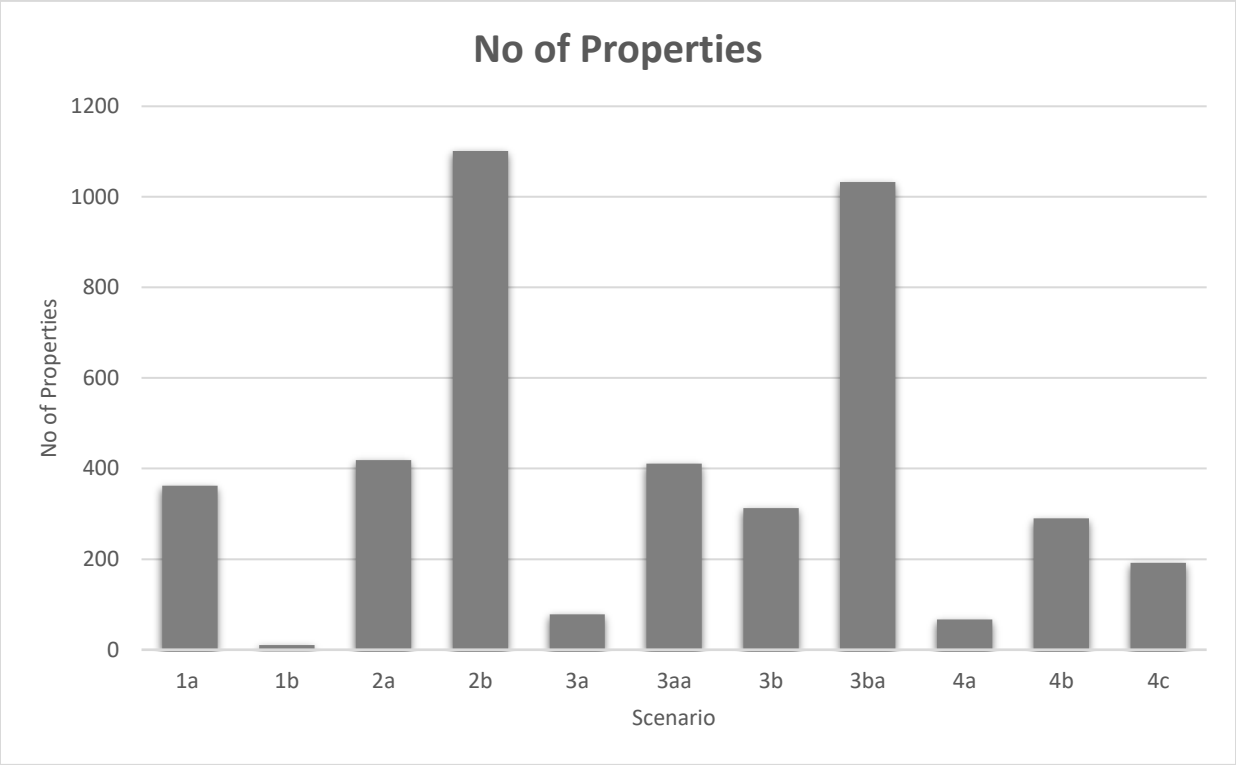
Buyouts			
Buyout	Whether property is Buyout	Binary	ProPublica
Buyout_Amt	How much property was bought out	Ratio	ProPublica
Buyout_Yr	Year property was bought out	Ratio	ProPublica
Buyout_Prg	Program of Buyout payments	Ratio	ProPublica
Buyout_num	Number of buyouts	Ratio	ProPublica
Buyout_dis	Distance to existing buyouts	Ratio	GIS
Flood claims			
Claim	Previous floodclaims for property	Binary	NFIP (claims)
Claim_num	Number of floodclaims	Ratio	NFIP (claims)
Claim_yr	Year of floodclaim	Ratio	NFIP (claims)
Claim_bld	Building pay of previous floodclaim	Ratio	NFIP (claims)
Claim_cont	Content pay of previous floodclaim	Ratio	NFIP (claims)
Repetitive Claims			
Reptv	Whether repetitive loss	Binary	NFIP (Repetitive loss)
Reptv_num	Total number of NFIP claim	Ratio	NFIP (Repetitive loss)
Reptv_bld	Total building pay from repetitive claims	Ratio	NFIP (Repetitive loss)
Reptv_con	Total content pay from repetitive claims	Ratio	NFIP (Repetitive loss)
Reptv_avg	Average amount of repetitive loss payments	Ratio	NFIP (Repetitive loss)
Reptv_mitg	Whether property is mitigated	Binary	NFIP (Repetitive loss)
Harvey Claims			
Harv	Whether property filed NFIP claim from Harvey	Binary	FEMA
Harv_clm_dpt	Depth of water from NFIP Claims data	Ratio	FEMA
Harv_bldg	Building claims from Hurricane Harvey	Ratio	FEMA
Harv_cont	Content claims from Hurricane Harvey	Ratio	FEMA
Loss Estimates			
Bld_Loss	Building Loss Estimates calculation	Ratio	Hazus
Cont_Loss	Content Loss Estimates calculation	Ratio	Hazus
Totals (Major Final Variables)			
Harv_ind	Inundation from Harvey in ft	Ratio	FEMA?
Reptv_tot	Total amount of repetitive loss payments	Ratio	NFIP (Repetitive loss)
Claim_tot	Total amount of previous floodclaim	Ratio	NFIP (claims)
Harv_tot	Claims from Hurricane Harvey	Ratio	NFIP
Tot_Loss	Total Loss Estimates calculation	Ratio	Hazus
Damages	Harvey claims, else, Hazus estimates	Ratio	NFIP-Hazus

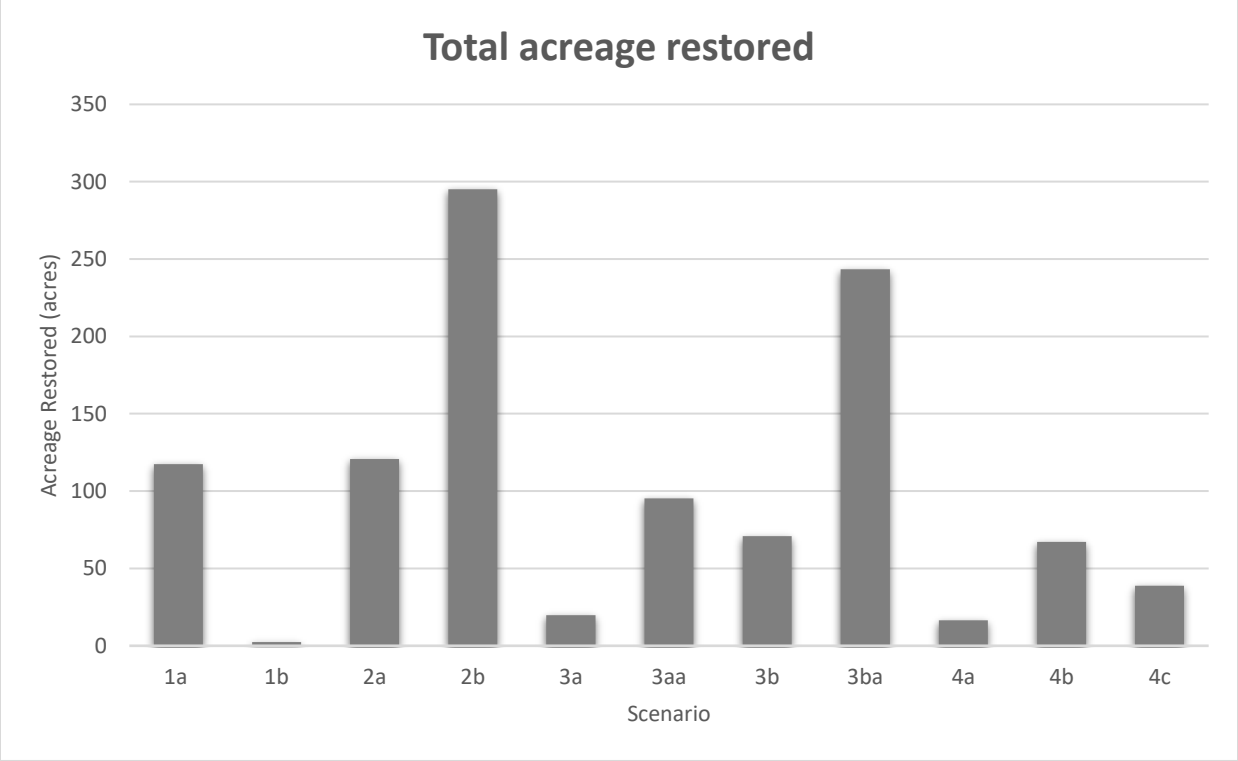
Appendix 2: Number of properties and damage to market value ratio across scenarios



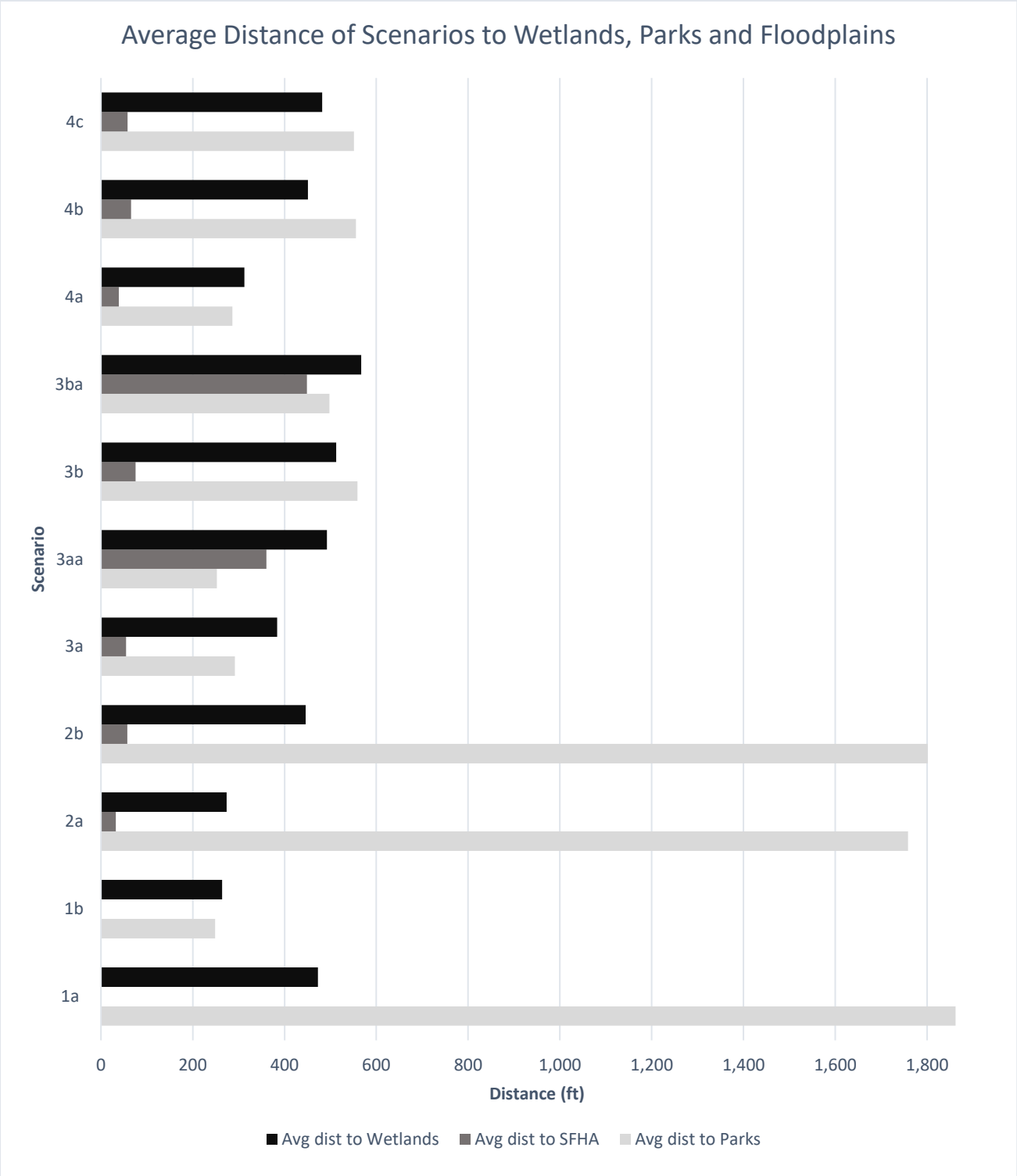


Appendix 3: Number of properties and acreage restored to open space across scenarios





Appendix 4: Average distance of candidate buyouts to floodplains, wetlands, and parks



Appendix 5: All candidate buyouts from all scenarios and SVI map of Harris county